SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Special Features

Bactericidal Effects of Chlorine—Hess et al.

O–RP of Chlorinated Sewage—Keefer and Meisel

Activated Sludge Studies—Smith

Oxygen Consumed Test Evaluation—Roberts and Sanderson

Toxicity of Metals to Fish—Doudoroff and Katz

JULY, 1953—VOL. 25, No. 7

Make Plans to Attend

TWENTY-SIXTH ANNUAL MEETING

OF THE

FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

IN CONJUNCTION WITH

FLORIDA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

BAYFRONT AUDITORIUM

MIAMI, FLORIDA

October 13-16, 1953

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FSIWA Housing Committee
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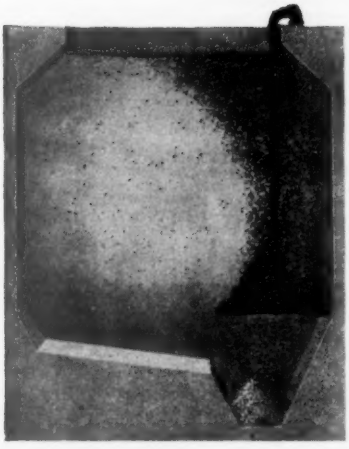
indicating at least first, second, and third hotel choices. Confirmation of the reservation will be received directly from the hotel accepting the reservation.

CHICAGO SEWAGE EQUIPMENT

AER-DEGRITTER



The only method of removing grit and sand from sewage without mechanical equipment is provided by the Aer-Degritter. The velocity of flow is controlled by air introduced through Swing Diffusers and Precision Diffuser Tubes. All sand of 0.2 mm. (65 mesh) and larger is washed and deposited in the bottom of the tank.

Less than 10% volatile matter and only a negligible trace of putrescible organics remains in the grit removed. Aer-Degritters may be installed ahead of all mechanical equipment because coarse sewage material will not interfere with the operation of the Aer-Degritter or affect the hydraulic design of the plant.

The basic features of the Aer-Degritter are:

- MAXIMUM REMOVAL
- CLEAN GRIT
- NO MECHANISM
- LOW COST
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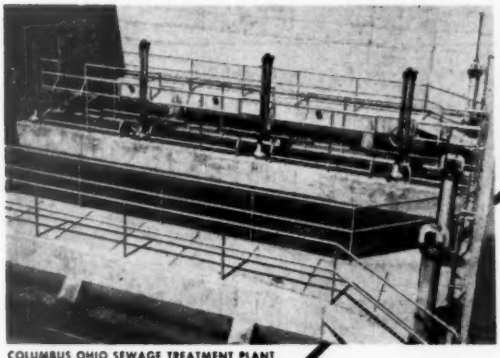
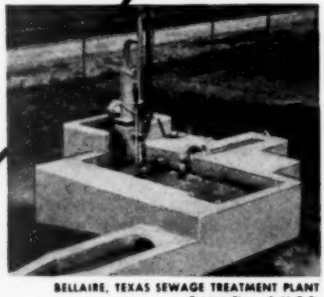
- AIR CONTROLLED VELOCITIES INDEPENDENT OF FLOW

52 INSTALLED IN TWO YEARS



COLUMBUS OHIO SEWAGE TREATMENT PLANT
Design Flow 160 M.G.D.
PAUL A. UHLMANN & ASSOCIATES
Consulting Engineers



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Design Flow 8 M.G.D
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SEWAGE AND INDUSTRIAL WASTES

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A monthly Journal devoted to the advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of such works.

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For batch or automatic processing, our equipment includes all necessary components.

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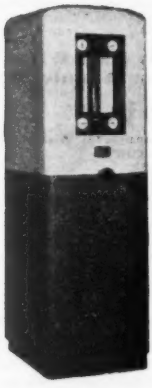

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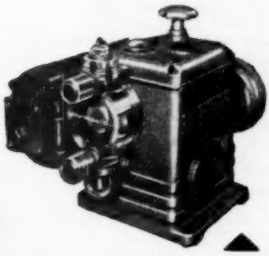

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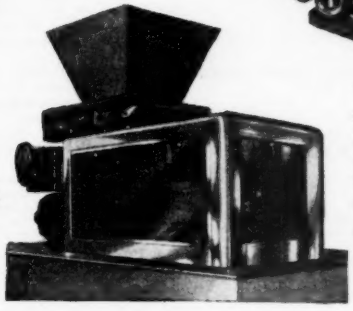

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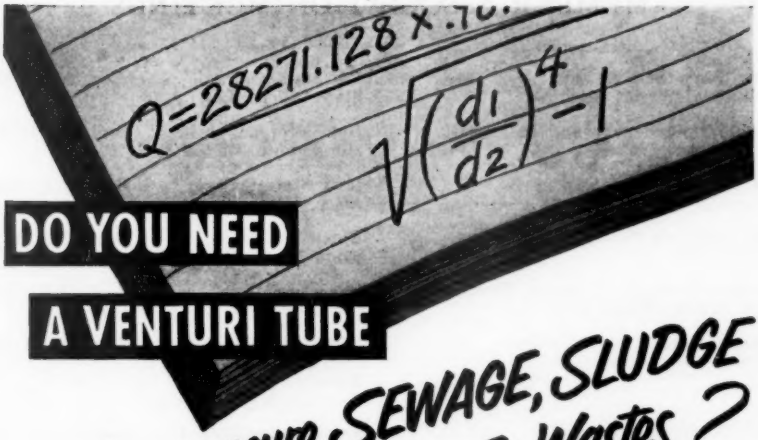

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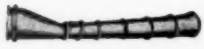
A VENTURI TUBE
to measure SEWAGE, SLUDGE or TRADE Wastes?

1. A specially designed Venturi Tube for sewage flow with cast-iron upstream section and steel-plate downstream cone.

2. Flat-invert design with long downstream recovery cone for sewage and sludge measurement.



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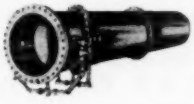

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There is a type to suit your needs—whether for sewage, sludge, process liquors, or trade wastes.

Your request for a solution to any measuring problem will bring a prompt reply. Write to Simplex Valve & Meter Company, 6719 Upland Street, Philadelphia 42, Pennsylvania.

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Pennsylvania Sewage and Industrial Wastes Assn.	Pa. State College, State College, Pa.	Aug. 26–28, 1953
West Virginia Sewage and Industrial Wastes Association	Hotel Morgan, Morgantown, W. Va.	Sept. 2–3, 1953
Iowa Sewage Works Assn.	Iowa State College, Ames, Iowa	Sept. 2–4, 1953
Rocky Mountain Sewage Works Association	Hotel La Fonda, Santa Fe, N. M.	Sept. 21, 1953
Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.	Owensboro Hotel, Owensboro, Ky.	Sept. 21–23, 1953
Michigan Sewage and Industrial Wastes Association	Michigan State College, Kellogg Center, East Lansing, Mich.	Sept. 21–23, 1953
South Dakota Water and Sewage Works Conference	Alex-Johnson Hotel, Rapid City, S. Dak.	Sept. 22–24, 1953
Missouri Water and Sewerage Conference	Elms Hotel, Excelsior Springs, Mo.	Sept. 27–29, 1953
North Dakota Water and Sewage Works Conference	Leland Parker Hotel, Minot, S. Dak.	Oct. 1–2, 1953

TWENTY-SIXTH ANNUAL MEETING

Federation of Sewage and Industrial Wastes Associations
in conjunction with
Florida Sewage and Industrial Wastes Association
Municipal (Bayfront Park) Auditorium, Miami, Florida
October 13–16, 1953

Address hotel reservation requests to: FSIWA Convention Housing Bureau, 320 N.E. Fifth Street, Miami, Florida

Canadian Institute on Sewage and Sanitation	General Brock Hotel, Niagara Falls, Ont., Can.	Oct. 26–28, 1953
New England Sewage and Industrial Wastes Association	Wannamoisett Country Club, 96 Hoyt Avenue, East Providence, R. I.	Nov. 5, 1953
Pacific Northwest Sewage and Industrial Wastes Association	Hotel Chinook, Yakima, Washington,	Nov. 5–7, 1953
North Carolina Sewage and Industrial Waste Association	Sheraton Hotel, High Point, N. C.	Nov. 9–11, 1953
Nebraska Sewage and Industrial Wastes Association	Hotel Capital, Lincoln, Nebr.	Nov. 12–13, 1953
Oklahoma Water, Sewage and Industrial Wastes Conference	Okla. A & M College, Stillwater, Okla.	Nov. 16–20, 1953

Briefs from the YEOMANS GUARD

Across the board— WIN, PLACE, and SHOW: the Treatment Plant at Tupelo

Take an appreciative look at these figures:

Daily flow	0.999 MGD
Raw sewage B.O.D.	286 ppm
Raw Sewage, suspended solids	216 ppm
Final effluent B.O.D.	31 ppm
Final effluent, suspended solids	34 ppm
Overall reduction B.O.D.	89%
Overall reduction, suspended solids	84%

These are average figures, reported from August '52 to January '53, inclusive, of operating results at the treatment plant in Tupelo, Mississippi.

It's a Yeomans plant—consists of a primary Spiraflo Clarifier, an Aero Filter Distributor and final Spiraflo Clarifier; plus a full quota of necessary pumps. It handles industrial wastes and domestic.

Simplicity of operation was a prime requisite; and the plant operates automatically with electrical control.

Further, its high efficiency is matched by its exceptional economy.

Still more, it's a sightly plant—bespeaks an alert, heads-up well managed community.

A full report covering plant details and performance data on request.

☐ Please send Tupelo report.

Four Aero-Filters Purify Domestic and Industrial Wastes at Rochester, Minn.

That standard type units lend themselves to special combinations for off-standard needs is well demonstrated by the sewage treatment plant at Rochester, Minnesota.

A strong probability that wastes from milk-processing plants, present in the sewage, would quickly become septic made it necessary to short-cut standard purifying procedure in order to hasten oxidation. For that reason basic treatment by rotary screens instead of conventional settling tanks delivers the sewage in the shortest possible time to four Yeomans high capacity Aero-Filters.

By this means oxidative purification is started much sooner, and the filter's work is made much easier.

With a complete line of standard units of every type—activated sludge process or high-capacity trickling filters—Yeomans engineers can assist in designing a plant custom-fitted to meet special requirements: a unique advantage.

Good business—consult Yeomans.

Centrifugal Pump or Pneumatic Ejector—Yeomans Can Recommend Either

When you submit to Yeomans any problem of handling material by pumping it, you can be entirely sure that you'll get an unbiased recommendation—as to centrifugal pump or pneumatic ejector.

> Yeomans engineering attention focuses on the character of material to be pumped and on other technical aspects of the job to be done—in order to determine which type of equipment will perform most efficiently, dependably and at lowest cost.

This claim of objectivity is, to be sure, common to practically all equipment manufacturers; but here it has added significance because Yeomans builds both centrifugals and pneumatics.

In all other respects a Yeomans recommendation is enthusiastically biased—because we are utterly convinced that Yeomans Pumps—either centrifugals or pneumatics are the best pumps built.

The Yeomans Guard, published several times a year, is a compendium of news and useful information covering the pumping of materials and the treatment of wastes, both domestic and industrial. We shall be pleased to send you the current issue if you'd care to have it. Ask your local Yeomans Representative—listed in the telephone book yellow pages under "Pumps"—or write direct.

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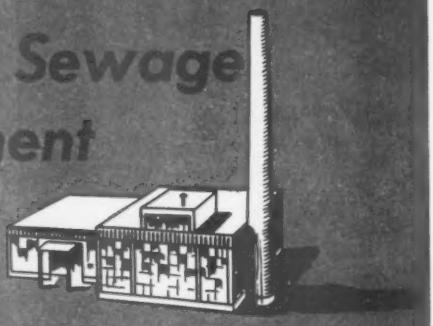
How to . .

. . Streamline Sewage Treatment



Dry and/or Burn Sludge with Nichols Multiple Hearth dryer-incinerators. Burn sewage sludge to a sterile ash or dry it for use as a fertilizer.

Use Proved Adaptable Equipment . . . the Nichols Multiple Hearth furnace successfully incinerates sludge in liquid, thickened, raw or digested state. Assures simple, positive, dependable and economical sludge disposal.

Have a Compact, Attractive Plant such as is made possible by use of the Nichols Multiple Hearth Dryer-Incinerator. Unsightly, space-wasting sludge beds, lagoons, dumps and digesters can be eliminated.

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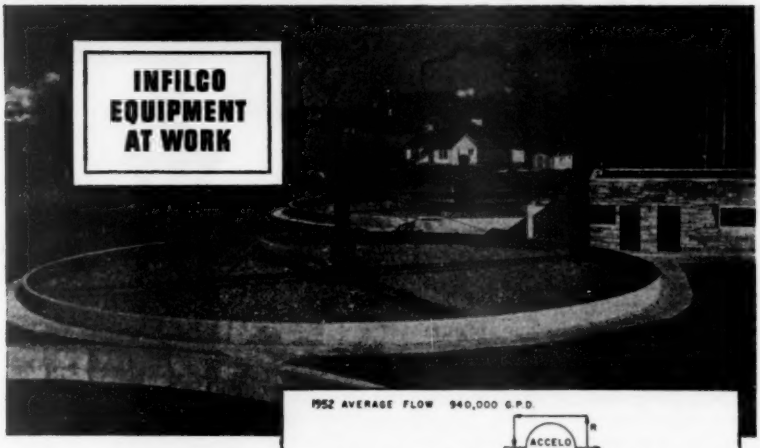
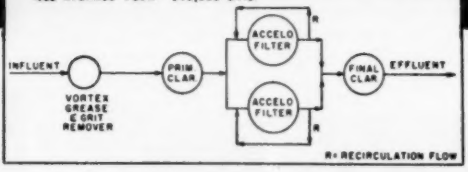


1952 AVERAGE FLOW 940,000 G.P.D.



Here's how WASHINGTON, IND.

solved its sewage problems...

Like many other small-but-growing communities, Washington, Indiana, required sewage treatment facilities able to do a complete job at low cost.

Working with J. B. Wilson, Consulting Engineer, Indianapolis, they achieved this effective, economical operation. The Vortex Grease and Grit Remover and PD Clarifier effect a 72% BOD reduction. Low-cost secondary treatment is accomplished through direct recirculation around Accelo® Filters.

AVERAGE OPERATING DATA FOR 1952:

Analysis	Raw Sewage	Primary Effluent	Plant Effluent
5-Day BOD	129	36	21
Suspended Solids	114	29	21

Infilco equipment and processes can solve your sewage problems...

Send this coupon for more information

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Plants in Chicago and Joliet, Illinois

FIELD OFFICES IN 28 PRINCIPAL CITIES

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CITY_____ STATE_____

LOCK JOINT

the ideal pressure pipe

for sewer force mains

Through the years Lock Joint has proven itself in water supply and transmission mains—and now more and more sanitary engineers are realizing its value for sewer force mains. It withstands high internal pressures and external loads, resists corrosion, tuberculation and rupture, has watertight flexible joints and will maintain a high carrying capacity for an estimated life of over 100 years.

Its performance is unexcelled, yet this high quality pipe is low in first cost and is virtually free from repair and maintenance charges. For top performance at rock bottom cost, specify Lock Joint Prestressed Concrete Cylinder Pipe for your next sewer force main project.

Lock Joint Prestressed Concrete Cylinder Pipe readily withstands the shocks of heavy city and highway traffic.

Its ability to withstand heavy backloads frequently makes it possible to lay Lock Joint Prestressed Concrete Cylinder Pipe in deep cuts without special bedding. The speed with which it may be laid and the fact that it can be immediately backfilled usually makes it unnecessary to sheet the trench.

SCOPE OF SERVICES—*Lock Joint Pipe Company specializes in the manufacture and installation of Reinforced Concrete Pressure Pipe for Water Supply Distribution Mains in a wide range of diameters as well as Concrete Pipes for Sanitary Sewers, Storm Drains, Culverts and Subaqueous Lines.*

LOCK JOINT PIPE COMPANY

Est. 1905

P. O. Box 269, East Orange, N. J.

PRESSURE PIPE PLANTS:
Wharton, N. J., Turner, Kan., Detroit, Mich.

BRANCH OFFICES: Casper, Wyo. • Cheyenne, Wyo. • Denver, Col. Kansas City, Mo. • Valley Park, Mo. • Chicago, Ill. • Rock Island, Ill. Wichita, Kan. • Kenilworth, N. J. • Hartford, Conn. • Tucumcari, N. Mex. • Oklahoma City, Okla. • Tulsa, Okla. Beloit, Wis. • Hato Rey, P. R.

LOCK JOINT
Reinforced Concrete
PRESSURE PIPE

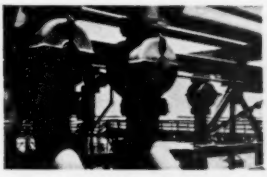
Non-retarded straight-through flow

...is guaranteed by A.C.F.'s Round Port Valves because the valve opening is *exactly* the same size and shape as the pipe itself.

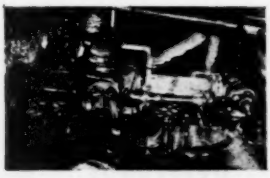
As a result you get full capacity flow of heavy viscous ladings with no loss in head pressure. Materials in suspension have no abrasive effect.

Full pipe area and the non-wedging effect of CYLINDRICAL PLUG DESIGN is also available in A.C.F. Rectangular Port Valves. It will pay to get all the facts about *both* before you buy. Call your nearby A.C.F. Representative now.

IN PETROLEUM AND GAS INSTALLATIONS A.C.F. Valves provide full flow with no pressure loss, fastest operation.



IN PROCESSING A.C.F. Round Port Valves are ideal for such materials as cement slurry with straight-through uninterrupted flow.

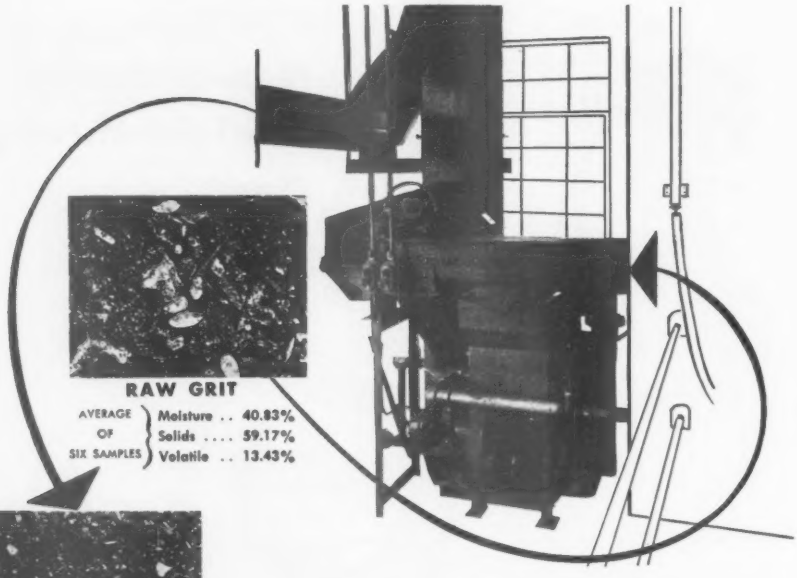


TWELVE YEARS OF SERVICE for these A.C.F. Valves handling hot asphalt is evidence of service-free performance.

a.c.f. CYLINDRICAL FULL PIPE AREA PLUG VALVES

Write for Catalog 4-SI. American Car and Foundry Company, Valve Division, 1501 E. Ferry Ave., Detroit 11, Michigan.

Representatives in 50 Principal Cities



RAW GRIT

AVERAGE OF SIX SAMPLES	Moisture ..	40.83%
	Solids	59.17%
	Volatile ..	13.43%

WASHED GRIT

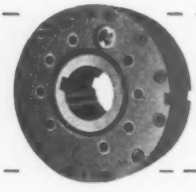
AVERAGE OF SIX SAMPLES	Moisture ..	20.22%
	Solids	79.78%
	Volatile ..	2.11%

solve your grit problem with JEFFREY "JIGRIT"

The Jeffrey "JIGRIT" Washer solves the disposal problems of odors, fly nuisance and burying expense. It produces an inoffensive washed grit that can be used for Fill, Road-ways, Walkways, etc. Grit channels, which are designed to settle out 65 mesh inorganic matter, settle out considerable organic matter, as well as make raw grit unsuited to open disposal. "JIGRIT" comes in three sizes: #1 (to 20 cu. ft. per hour); #4 (to 120 cu. ft. per hour); and #9 (to 280 cu. ft. per hour).

Investigate the Jeffrey "JIGRIT" now by writing for Cat. 833.

"HYDROLESE" PREVENTS OVERLOADS



The Jeffrey "HYDROLESE" Hub is big news in Sanitation Circles. It gives positive protection against overloads and eliminates troublesome shear pins. "HYDROLESE" can be: Adjusted to meet various load conditions . . . can be provided with visual warning . . . readily reset. It will not burn up. It carries a definite torque load (maximum of 20,000 lbs.) for speeds up to 20 R.P.M.

THE JEFFREY MANUFACTURING CO.

ESTABLISHED 1877

Columbus 16, Ohio

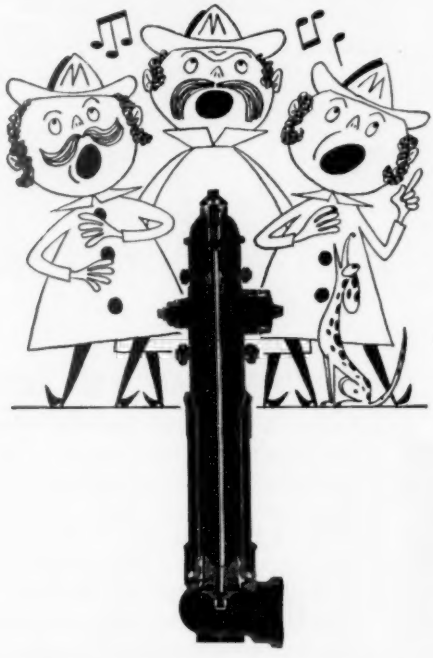
sales offices and distributors in principal cities

PLANTS IN CANADA, ENGLAND, SOUTH AFRICA

IF IT'S MINED, PROCESSED OR MOVED

. . .IT'S A JOB FOR JEFFREY!

Installed in Grandfather's Day— Still Providing Full Community Protection



MATHEWS
HYDRANTS

Made by R. D. Wood Company

Public Ledger Building, Independence Square
Philadelphia 5, Pa.

Manufacturers of "Sand-Spun" Pipe (centrifugally cast in sand molds) and R. D. Wood Gate Valves

• Mathews Hydrants are built to last. They are so simple and well constructed that there's virtually nothing to go wrong.

• Maintenance is easy, too. Operating thread can be lubricated during spring and fall inspections.

• When the time comes to modernize, it is a simple matter to remove the old barrel and replace it with a modern one. The job is done in a few minutes without digging or breaking the pavement.

No Other Hydrant Offers So Many Essential Features

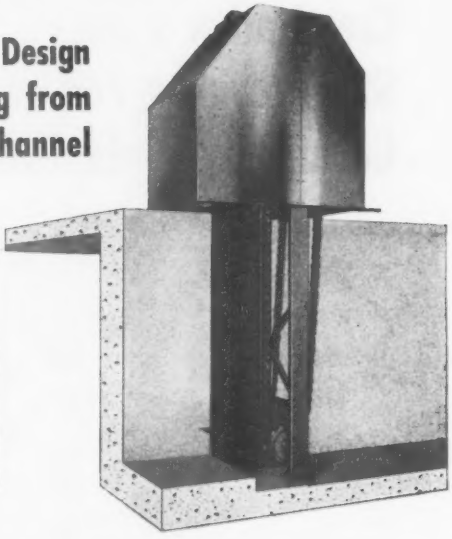
Compression type valve prevents flooding • Head turns 360° • Replaceable head • Nozzle sections easily changed • Nozzle sections easily raised or lowered without excavating • Protection case of "Sand-Spun" cast iron for strength, toughness, elasticity • Operating thread only part to be lubricated • All working parts contained in removable barrel • A modern barrel makes an old Mathews good as new • Available with mechanical-joint pipe connections

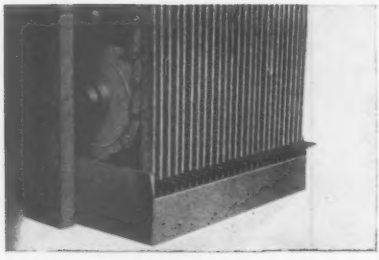
150th anniversary

COMPLETELY AUTOMATIC MECHANICALLY CLEANED

UNIT BAR SCREEN

Exclusive Pivoted Rake Design Assures Positive Raking from Absolute Bottom of Channel





Horizontal position of rake teeth at the beginning of cleaning cycle accomplishes raking from absolute bottom of channel. Gets under and picks up all screenings—does not push them away • Note unobstructed channel approach.

Rake making 45° radial drop to discharge screenings into trough—Note shear pin hub with tool steel shaft and hub inserts for perfect shear action.

THE "AMERICAN" UNIT SCREEN

Completely automatic with a limit switch which stops operation with the rake out of the flow when time control or water level control cycles have been completed • Easily installed as a unit in concrete channels • Total height of unit from mounting floor to motor base is only five feet • The entire above-floor structure is enclosed with stainless steel panels secured by quick opening fasteners to permit easy inspection and access.

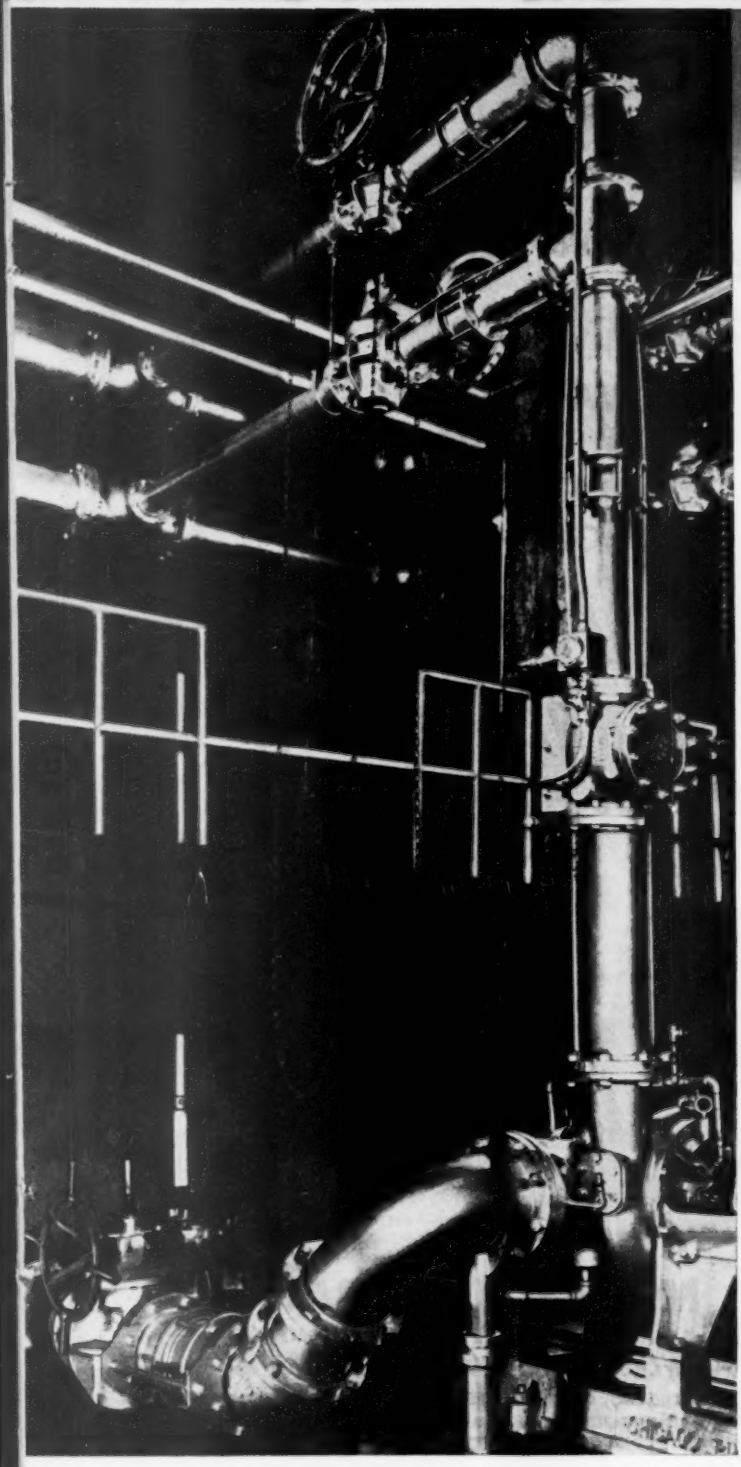
Send for TECHNICAL SUPPLEMENT "MS"

AMERICAN WELL WORKS

IN OUR 85TH YEAR
110 North Broadway
AURORA, ILLINOIS

Pumping, Sewage Treatment, and Water Purification Equipment
RESEARCH • ENGINEERING • MANUFACTURING

Offices: Chicago • New York • Cleveland • Cincinnati • Kansas City • Sales Representatives throughout the World



FROM TOP TO BOTTOM

this sewage plant is Nordstrom equipped

In the sewage treatment plant shown in this picture, Nordstrom valves are installed on all types of lines from intake to discharge.

Why? Because Nordstroms are protected by a film of pressurized lubricant.

This lubricant surrounds seat ports preventing leakage . . . it protects the vital seating surfaces of a Nordstrom from wear, corrosion, erosion or abrasion . . . it keeps the valve ready to open or close with a quick quarter-turn at any time—reason enough to standardize on Nordstroms.

If you are building a new sewage treatment plant or replacing the valves in your present one, call your Nordstrom representative for an estimate. Rockwell Manufacturing Company, Pittsburgh 8, Pa.

ROCKWELL Built Nordstrom Valves

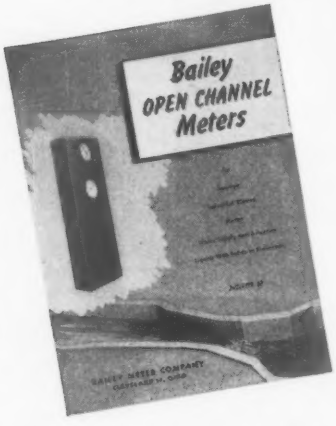
Lubricant-Sealed for Positive Shut-Off

Another Rockwell Product

For trouble-free, low cost measurement of—

SEWAGE
INDUSTRIAL WASTES
SLUDGE
IRRIGATION WATER

BAILEY
OPEN CHANNEL METERS
Offer These Advantages:



1. Easy to Install
2. Retain Accuracy
3. Self-Cleaning
4. Adjustable Capacities
5. Totalize Multiple Flows
6. Chemical Feed Control
7. Flow and Ratio Controls

Ask for Bulletin 62

MU22

BAILEY METER COMPANY

1066 IVANHOE ROAD • CLEVELAND 10, OHIO

METERS and CONTROLS for SEWAGE and WATER

VENTURI TUBES, FLUMES, WEIRS, NOZZLES, ORIFICES • DIRECT MECHANICAL AND REMOTELY LOCATED REGISTERS • AIR-OPERATED, ELECTRONIC AND ELECTRIC CONTROLS.

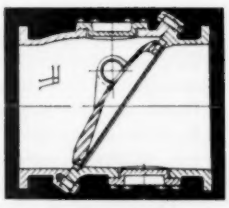
. . . here's how to get them out from under with

CHAPMAN *Tilting Disc* CHECK VALVES

Loosened pipe-joints are caused by hammering. And hammering is caused by valve-slam. But when a valve can't slam under usual piping arrangements . . . then you're free from the danger of line damage.

And this is all because of the Chapman Tilting Disc, with specially designed airfoil section that means light weight, and perfect balance in the open position, so it is easily held open in the flow . . . and then dropped quietly to a *cushioned closing* that does not even jar the line.

That's why certified tests from the country's top engineering schools and actual installations prove that Chapman Tilting Disc Check Valves reduce head-loss over regular swing-type checks. Check these tests for yourself . . . write for Catalog No. 30.



Cross-section of the Chapman Tilting Disc Check Valve. A feature of the design is that the disc seat lifts away from the body seat when opening, and drops into contact when closing, with no sliding or wearing of the seats.

The Chapman Valve Mfg. Co.

INDIAN ORCHARD, MASSACHUSETTS

EVERDUR STEMS:

TURN THEM EASILY–ONCE A DAY OR ONCE A YEAR. THEY RESIST CORROSION.

Rust and efficiency—like oil and water—don't mix. In gate and valve stems rust costs money. You avoid this by specifying stems made of Everdur*—*strong, rustproof and corrosion-resistant.*

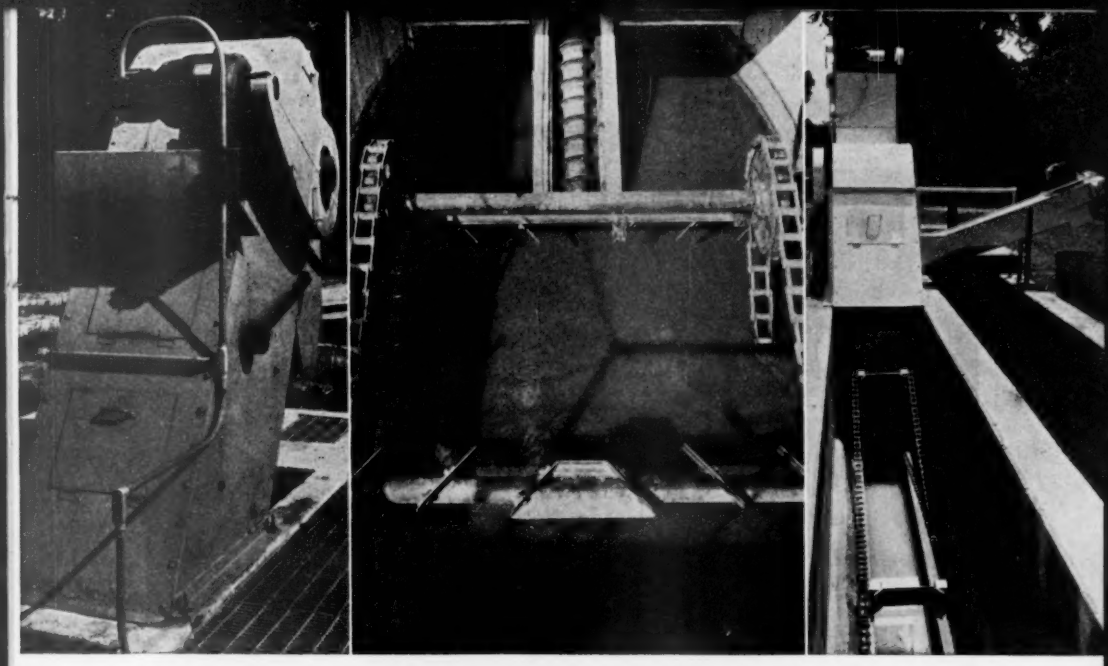
Everdur Copper-Silicon Alloys have long been fabricated into lightweight sewage and waterworks structures. Gates, screens, guides and bolts, weirs, float chambers, troughs, manhole steps and electrical conduit—all gain *extra* protection when made of Everdur.

Depending on the type or composition, you can work Everdur Alloys hot or cold, and readily form, forge, weld and machine them. They are available in plates, sheets, rods, tubes, electrical conduit and casting ingots.

Write for free booklet, "Everdur Copper-Silicon Alloys for Sewage and Waterworks Equipment." For practical advice on selecting the correct material for your equipment, consult our Technical Department. Their services are freely available. *The American Brass Company, Waterbury 20, Connecticut. In Canada: Anaconda American Brass Ltd., New Toronto, Ont.*

*Reg. U. S. Pat. Off. 53139A

EVERDUR
ANACONDA®
COPPER-SILICON ALLOYS
STRONG • WELDABLE • WORKABLE
CORROSION-RESISTANT



TRITOR SCREENS—At small sewage treatment plants—where grit creates a problem during storm flows, this one machine accomplishes the effective, low-cost removal of both screenings and grit.

STRAIGHTLINE GRIT CHAMBERS—For the removal of a clean, washed grit with a low putrescible content. The complete collection and thorough cleaning operation makes further handling unnecessary.

STRAIGHTLINE GRIT COLLECTORS—On this bucket type collector, wate sprays wash the grit from the bucket into a separate washing and dewater ing screw. Photo also shows Link-Bel Bar Screen.

How to get flexible, low-cost grit removal

LINK-BELT can give you equipment best suited to your requirements

DON'T let grit plug your pipe lines . . . wear out your pumps . . . take up valuable space in your digesters. Link-Belt builds effective grit removal equipment that assures both low costs and flexibility.

For example, with the Tritor Screen, a grinder may be used to shred the screenings when no grit is received. During storms, the grinder may be by-passed and grit and screenings disposed of by fill, burial or incineration. Similarly, the Straightline grit collector is designed either with a pitched flight collector and dewatering and washing screw discharging direct from the grit chamber—or with a bucket type collector for deep chambers.

In addition to grit handling and washing equipment, Link-Belt manufactures a complete line of equipment for water, sewage and industrial waste treatment plants. A call to the Link-Belt office near you will put you in touch with an experienced sanitary engineer. He'll work with your engineers, chemists and consultants—help you get the best in modern treatment equipment.

LINK-BELT COMPANY: Plants: Chicago, Indianapolis, Philadelphia, Colmar, Pa., Atlanta, Houston, Minneapolis, San Francisco, Los Angeles, Seattle, Toronto, Springs (South Africa), Sydney (Australia). Sales Offices in Principal Cities.

13,134

LINK-BELT

SANITARY ENGINEERING EQUIPMENT

whatever your Control problems...

IOWA

is ready to meet your every requirement...

IOWA Motor Operated Gate Valve . . .
Sewage plant influent

IOWA Gate and Check Valves . . .
Sewage pump discharge

IOWA Manually Operated Sluice Gate . . .
Settling basin drain

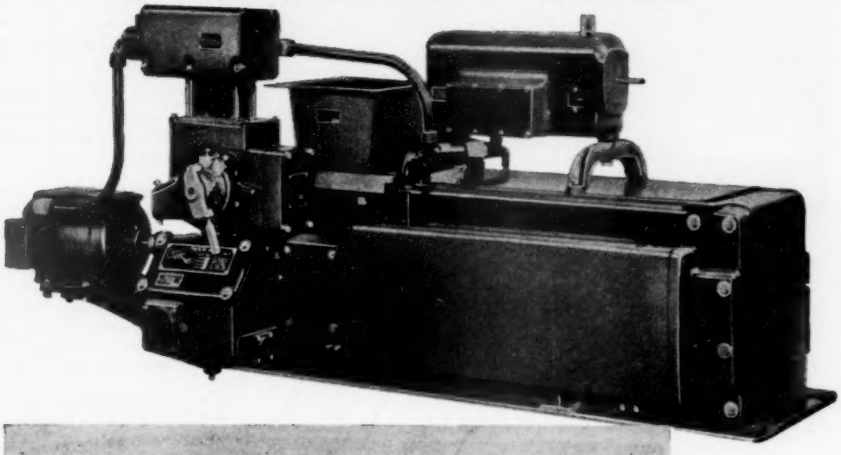
IOWA'S complete line of gate valves, check valves, flap valves, shear gates, mud valves and sluice gates is specially designed for severe and particular operating conditions in sewage disposal plants, sewage pumping stations or wherever sewage flow control is required. Let us help you solve your problems. Specify IOWA products and get the best.

IOWA VALVE COMPANY

201-299 N. Talman Ave., Chicago 80, Ill. • *A Subsidiary of James B. Clow & Sons*

The best "WEIGH" . . . is the MERCHEN way!

W&T Merchen Feeders give precision feeding of any waterworks chemical . . . *by weight.*



FEATURES:

—Continuous, minute-to-minute accuracy.

—Durable construction, sealed bearings and dust shields.

—Automatic built-in alarm switch.

—Knife edges and pivots tipped with special alloy for long life.

—Remote feed rate adjustment if desired.

—Adaptable to fully automatic proportional control.

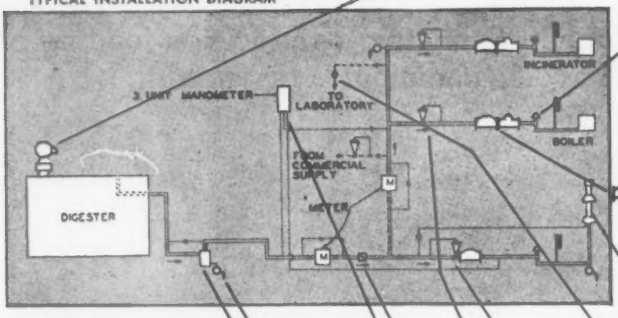
Hundreds of installations feeding waterworks chemicals, industrial chemicals and feed and flour ingredients have proved the accuracy and dependability of these belt-type gravimetric feeders.

M-24

USE W&T FEEDERS FOR
Dependable Chemical Control

WALLACE & TIERNAN
COMPANY, INC.
CHLORINE AND CHEMICAL CONTROL EQUIPMENT
NEWARK 1, NEW JERSEY — REPRESENTED IN PRINCIPAL CITIES

TYPICAL INSTALLATION DIAGRAM



"VAREC" Pressure Relief and Vacuum Breaker Valve with Flame Arrester — Fig. 5800C — Relieves excess pressures and vacuum in digesters and protects vessels from outside fires.

"VAREC" Explosion Relief Valve—Fig. 70 — Relieves sudden surges in pressure from explosion or momentary plant fluctuations.

"VAREC" Flame Trap Assembly—Fig. 450—Prevents flame propagation in piping.

"VAREC" Waste Gas Burner—Fig. 236, 237 or 238—Efficiently burns all excess gas.

"VAREC" Flame Check — Fig. 51A or 52A — Prevents flashback from burner pilot or laboratory burners.

"VAREC" Pressure Relief and Flame Trap Assembly—Fig. 440—Permits excess pressure to be wasted through gas burner and prevents flame flashback from burner.

"VAREC" Pressure Reducing Regulator—Fig. 187 or 387—Controls pressure of gas going to utilization equipment.

"VAREC" Check Valve —Fig. 211 or 211A—Controls direction of gas flow.

"VAREC" Manometer —Fig. 215, 215A, 216 or 216A — Indicates system pressures.

"VAREC" Drip Trap—Fig. 245 or 248.

"VAREC" Sediment Trap — Fig. 230, 232 or 233 — Keeps lines drained and free from moisture.

Plan with "Varec" Symbols of Safety

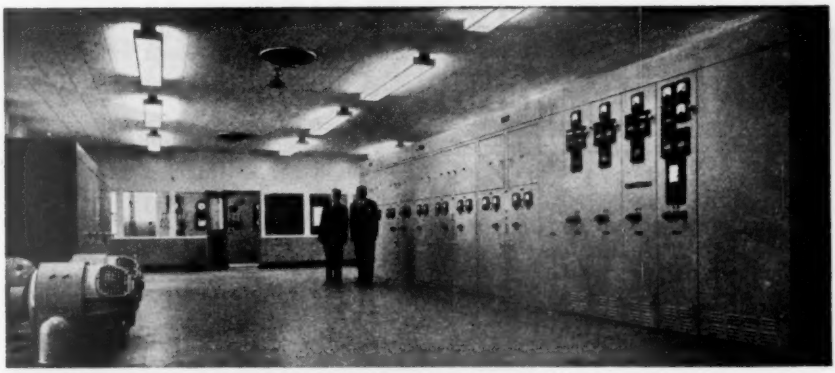
FOR GAS CONTROL THROUGHOUT YOUR SEWAGE TREATMENT PLANT

PROVED and APPROVED "Varec"

THE VAPOR RECOVERY SYSTEMS COMPANY

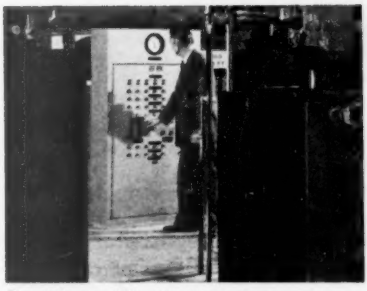
COMPTON, CALIFORNIA, U. S. A.

S-10 *Available from Authorized Sewage Equipment Agents throughout U. S. and Canada.*



Typical of modern G-E equipment is this switchgear and Limitamp control lineup at a new west coast plant.

3-way aid for your Clean Waters plan



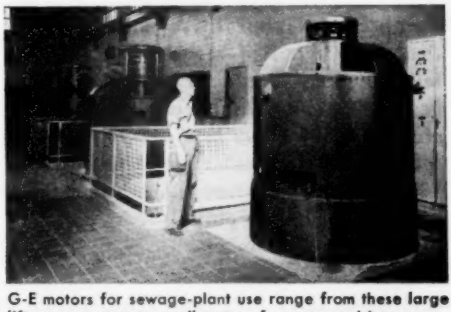
Special control like this chlorinator panel is part of complete G-E equipment for sewage plants.

Available now to all communities faced with the need for new or expanded sewage-treatment facilities is this three-way help from General Electric:

1. **Community-action program,** including the film *Clean Waters* to aid you in increasing public support for necessary new projects.
2. **Engineering assistance** to your consultants or engineers in electrical-system planning.
3. **Co-ordinated electrical equipment** supplied from the complete G-E line of motors, control and power distribution equipment.

To take advantage of this complete service, contact your nearest G-E Apparatus Sales Office early in the planning of your project. General Electric Co., Schenectady 5, N. Y. 666-75

Clean Waters program consists of film, manual *Modern Sewage Treatment,* handout leaflets.



G-E motors for sewage-plant use range from these large lift-pump motors to small motors for process drives.

Engineered Electrical Systems for Sewage Plants

GENERAL ELECTRIC

Tests Prove

CLAY PIPE is detergent-proof!

Of course it is. Clay pipe is chemically inert. Detergents can't weaken it, soften it, or separate its particles. All they can do is keep it clean.

Comparative laboratory tests show that *other* types of sewer pipe may fail, however, in contact with detergents. One non-clay material failed after only 500 hours in a *one-percent solution* of a popular detergent at "dishwater temperature." A lab technician was able to pull it apart and shred it with his fingers.

Important? You bet it is! Hundreds of thousands of gallons of detergent solutions pour into a city's sewers every day. There's no *safe* substitute for Vitrified Clay Pipe. It's the *only* chemically inert pipe . . . the only pipe that can't wear out. It stays rock-hard . . . glass-smooth . . . die-straight, year after year in the ground. *And it's guaranteed for half a century!*

NATIONAL CLAY PIPE MANUFACTURERS, INC.
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Vitrified CLAY PIPE NEVER WEARS OUT!

ESSENTIAL • ECONOMICAL • EVERLASTING

C-353-3

SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 25 | **July, 1953** | **Number 7**

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Sewage Works

BACTERICIDAL EFFECTS OF SEWAGE CHLORINATION *

I. Statistical Analyses of Plant Data

By Seth G. Hess, Alex N. Diachishin and Paul De Falco, Jr.

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The past century has seen the development of manifold uses of chlorine to the point where it is now recognized as a major tool in many phases of the treatment of sewage and industrial wastes.

Of these applications of chlorine, probably the most significant is its use in the disinfection of sewage effluents. Over the years a considerable amount of study has been devoted to improving the efficiency of this process. Attempts have been made by a number of researchers to determine the reactions involved in disinfection in order to provide a scientific basis for the establishment of criteria necessary for the standardization of effluent chlorination practices.

Some recent studies have featured the extensive use of statistical techniques, which offer promise of yielding useful results. The statistical analyses described herein have been made in an attempt to facilitate the conformance of sewage treatment plants to the bacteriological standards of the Interstate Sanitation Commission, and in general to provide methods that enable compliance with any of the variety of bacterial standards in use today.

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Statistical Analyses

The data used in this study were abstracted from the records of the Interstate Sanitation Commission. These records consisted of the results of 15 years of routine field and laboratory examinations of samples collected at a number of sewage treatment installations. These examinations were conducted by the staff of the Commission in order to determine compliance with the Tri-State Compact, which charges the Commission with enforcing the provision that "All sewage discharged or permitted to flow into Class 'A' waters of the District shall first have been so treated as . . . to effect a reduction of organisms of the B. Coli group (intestinal bacilli) so that the probable number of such organisms shall not exceed one per cubic centimeter in more than fifty per centum (50%) of the samples of sewage effluent tested by the partially confirmed test. . . ."

The methods and procedures used by the staff of the Commission are in conformity with "Standard Methods" (1). Samples of plant effluent are collected in a sterile bottle at a point after all treatment processes and chlorination, usually just prior to discharge from the plant. Samples are inocu-

lated at the plant directly into lactose broth culture tubes in the appropriate dilutions. The dilutions used are governed for the most part by the chlorine residual in the samples determined by the ortho-tolidine test (on an aliquot). The samples are returned to the laboratory within 8 hr. and are then incubated at 35° C. The tubes are examined after 24 and 48 hr. and those showing evidence of the presence of gas are recorded as presumptive positives. Transfers are made of all positives to brilliant-green bile broth tubes, which are in turn incubated for 48 hr. at 35° C. All tubes showing the presence of gas when examined at 24- and 48-hr. intervals are recorded as positive in the confirmed test. All counts are determined by the use of Hoskins' (2) tables.

Residual chlorine determinations are in accordance with the ortho-tolidine method (1). All chlorine residual readings are taken at the plant site with the aid of comparators and disc standards. Residuals are read as close to the time of culture tube inoculation as is practicable. The residuals are total values, including both free and combined chlorine.

The results of nearly 5,000 coliform tests at approximately 100 treatment plants were available for statistical analysis. The residual chlorine readings and the corresponding coliform counts for individual plants were analyzed, and correlations utilizing the general type of curve shown in Figure 2 were computed. This curve is of the same type as noted in the studies of Tiedemann (3) and Eliassen and Krieger (4) (5) and is expressed as:

$$\log y = \frac{1}{a + b R} \quad \ldots\ldots (1)$$

in which

y = M.P.N.;
R = chlorine residual; and
a and b = constants.

To utilize Eq. 1 in a linear correlation analysis, it is necessary to transform it by letting

$$Y = \frac{1}{\log y} \quad \ldots\ldots (2a)$$

from which it follows that

$$Y = a + b R \quad \ldots\ldots (2b)$$

The curve represented by Eq. 1 displays a slope which continually decreases with increasing residual (see Figure 2). More bacteria, absolutely and percentage-wise, are killed for an increase of residual chlorine from 0.5 to 1.0 p.p.m. than for an increase from 1.0 to 1.5 p.p.m. It appears that the more susceptible bacteria are killed at first, with the hardier bacteria remaining. In accordance with Eq. 1, the process of chlorination can be construed as a grading action. Susceptible bacteria are continually culled from the bacterial population by an increase of chlorine residual; to kill the hardier individuals remaining requires greater and greater residuals.

Although Eq. 1 was used for most of the work presented herein, trial correlations were also calculated for

$$\text{Log M.P.N.} = a + b \log R \ldots (3)$$

$$\text{Log M.P.N.} = a + b \log R^2 \ldots (4)$$

$$\text{Log M.P.N.} = a + b R^2 \ldots\ldots (5)$$

$$1/\text{M.P.N.} = a + b R \ldots\ldots (6)$$

In the majority of the cases analyzed, the best agreement was obtained with Eq. 1.

Table I gives the values obtained from the analysis of individual plant data from each of 15 plants. In addition to the type of treatment, the efficiency on the basis of suspended solids and B.O.D. removals, and the number of samples analyzed, the following information has been included:

1. Intercept. The intercept is the value of 1/log M.P.N. that corresponds to a 0 residual when a mortality curve of the type of Eq. 1 is used to describe the data. The value of the intercept does not correspond to the initial num-

TABLE I.—Values Obtained by Analysis of Data from 15 Plants

Plant	Treatment	B.O.D. Removal (%)	S.S. Removal (%)	N	r	a^1	b^1	Variance
1	Primary	30	57	24	0.691	0.296	0.328	0.250
2	Primary	52	78	45	0.614	0.200	0.213	0.215
3	Primary	35	67	44	0.433	0.343	0.158	0.166
4	Primary	37	58	29	0.677	0.414	0.129	0.213
5	Secondary	77	86	28	0.410	0.218	0.245	0.276
6	Secondary	83	78	20	0.692	0.441	0.198	0.394
7	Primary	36	60	36	0.660	0.194	0.551	0.227
8	Primary	39	54	16	0.778	0.359	0.247	0.299
9	Primary	37	64	23	0.908	0.244	0.305	0.185
10	Primary	35	64	12	0.686	0.258	0.587	0.416
11	Primary	32	53	55	0.697	0.274	0.222	0.217
12	Primary	50	66	57	0.815	0.207	0.279	0.131
13	Primary	56	78	16	0.755	0.434	0.187	0.446
14	Primary	32	50	16	0.653	0.271	0.326	0.392
15	Primary	44	64	25	0.593	0.294	0.315	0.445

[1] Values of a and b refer to the specific values of these parameters in the general curve $1/\log \text{M.P.N.} = a + b\,R$.

ber of bacteria prior to chlorination. It is the statistically interpolated value at a 0 chlorine residual after chlorination. Although in all probability there is some gross relation between the intercept value and the original number of bacteria prior to chlorination, there is no constant of proportionality between these values. Data with 0 residuals are considered alike, even though these residuals may correspond to sewage samples with markedly different chlorine doses.

High values of the intercept a indicate a comparatively small number of bacteria at 0 residuals. The tabular values of a are computed on the basis of least squares and are equal to

$$a = \frac{\Sigma R \Sigma XY - \Sigma R^2 \Sigma Y}{[\Sigma R]^2 - N\Sigma R^2} \quad \ldots\ldots (7)$$

2. Slope. The slope value for a given plant is an indication of the rate at which bacteria are killed by the chlorination procedures. High values for the slope b indicate more rapid kills of bacteria than low values. The tabular values of b are computed on the basis of least squares when using a curve of the type represented by Eq. 1. The slope is equal to

$$b = \frac{\Sigma X \Sigma Y - N\Sigma XY}{[\Sigma X]^2 - N\Sigma X^2} \quad \ldots\ldots (8)$$

3. Variance. In general, variances describe the amount of dispersion of a given set of values. High values of the variance given in Table I indicate a larger dispersion of values for 1/log M.P.N. at any given value of the residual. Low values of the variance indicate that the range of the cluster of points at a given residual value is comparatively small. On the basis of least squares, for a curve of the type employed, the variance is equal to

$$\sigma_r = \sqrt{1 - r^2}\sqrt{\frac{\Sigma Y^2 - [\Sigma Y]^2/N}{N - 2}} \quad \ldots (9)$$

4. Correlation Coefficient. The correlation coefficient indicates the "goodness of fit" of data to the mortality curve used. A perfect correlation (one in which all of the data points lie exactly on the mortality curve) has a value of 1.0 for the correlation coefficient. Values are considered significant when the probability of occurrence by chance alone is from 1 to 5 per cent; that is, there is little possibility that the correlations were the result of a

fortuitous arrangement of the data. The tabular values of the correlation coefficient, computed on the basis of least squares, are equal to

$$r = \frac{\Sigma X\,Y - \Sigma X \Sigma Y/N}{\sqrt{[\Sigma X^2 - (\Sigma X)^2/N][\Sigma Y^2 - (\Sigma Y)^2/N]}} \quad \ldots\ldots\ldots\ldots (10)$$

High values of the coefficient in themselves do not necessarily indicate the best kind of curve describing the data. There may exist other curves which will occasion even greater values of the correlation coefficient.

Figure 1, illustrating the curves obtained for each of the plants, is a graphical presentation of the curves described in Table I.

Application to Plant Operation

For any of the curves of Figure 1, the chlorine residual necessary to maintain a given M.P.N. may be obtained. In Figure 2 (see Table II for curve data), a typical plant curve, the inter-

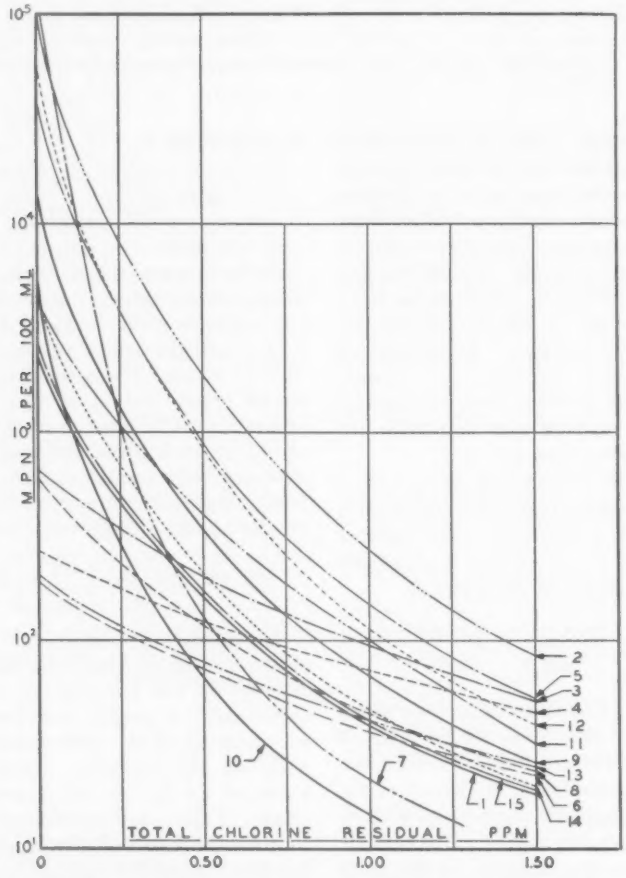

FIGURE 1.—Plant curves for M.P.N. *versus* residual chlorine.

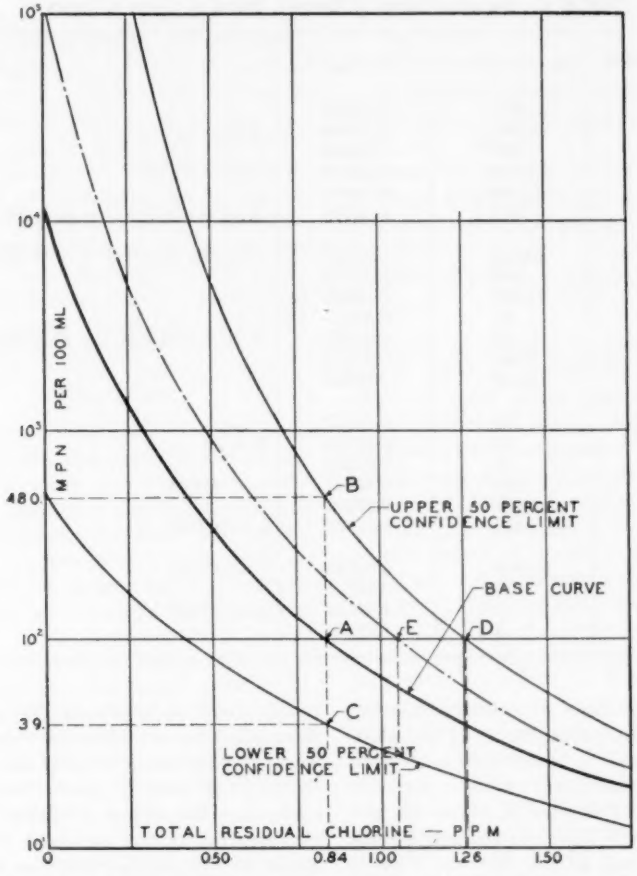

FIGURE 2.—Typical curves for M.P.N. *versus* residual chlorine at one plant.

section of the 100-per-100-ml. M.P.N. line with the curve at A gives the necessary residual, in this case 0.84 p.p.m.

However, this method does not take recognition of how well the curve represents the original data. Its use implies that a plant curve determined by the use of data points which have a wide scatter about the curve is as valid as a curve for which each of the data points is exactly on the curve. Actually, the exact position of a curve with widely scattered points is not as well-established as a curve with a relatively narrow scatter of points.

The amount of scatter of individual points about a curve can be taken into account by the use of confidence limits. Confidence limits are paired curves, of the same general shape as the parent curve, and contain within their limits a prescribed percentage of the total data points. For instance, 50 per cent confidence limits will enclose about 50 per cent of the data points. Fifty per cent confidence limits give the range of M.P.N. values that will occur 50 per

TABLE II.—Data for Curves of Figure 2, Based on Curve 9, Figure 1

Chlorine Residual (p.p.m.)	M.P.N./100 ml.	1/Log M.P.N.	
1.2	11,000	0.24744	
0.2	9,300	0.25199	$\Sigma R = 18.7$
0.6	390	0.38594	
0.1	9,300	0.25199	$\Sigma R^2 = 51.91$
0.5	2,400	0.29584	
0.4	910	0.33795	Σ [1/log M.P.N.] = 11.31698
0.1	46,000	0.21447	Σ [1/log M.P.N.]^2 = 9.6970342272
0.2	910	0.33795	
0.1	24,000	0.22830	
0.8	91	0.51045	
1.0	36	0.64255	Σ [R/log M.P.N.] = 20.383446
0.4	4,600	0.27302	
0.2	4,600	0.27302	
0.5	230	0.42342	
1.2	36	0.64255	$N = 23$
0.8	36	0.64255	
0.3	230	0.42342	$r = 0.9084$
0.2	4,600	0.27302	
0.4	430	0.37973	$a = 0.2444$
0.3	16,000	0.23786	$b = 0.3046$
0.2	170	0.44834	
6.0	3.6	1.79759	$\sigma_r = 0.1853$
3.0	3.6	1.79759	

cent of the time if certain chlorine residuals are maintained. If the chlorine residual is maintained at 0.84 p.p.m. at the plant whose curve is illustrated in Figure 2, about 50 per cent of the M.P.N. values will be between 480 and 39 per 100 ml. This is the range between the points of intersection of the upper and lower confidence limit curves and the 0.84-p.p.m. residual line at B and C, respectively.

To maintain M.P.N. values that are exceeded only in some small percentage of instances, the intersection point of the required bacterial density line with the upper confidence limit at point D can be utilized. If the chlorine residual is maintained at 1.26 p.p.m.; 50 per cent of the M.P.N. values will be between 21 and 100 per 100 ml; about ½ of 50 per cent will be greater than 100 per 100 ml. In all, about 75 per cent of the M.P.N. values will be less than 100 per 100 ml.

The desirability of accurate data points from a practical viewpoint is illustrated by confidence limits. If it were possible to determine the parent curve in Figure 2 more accurately, such that the upper confidence limit, represented by the dot-dash curve, is closer to the parent curve, a residual of only 1.05 p.p.m. (point E) rather than 1.26 p.p.m. would have to be maintained in order that 75 per cent of the M.P.N. values be 100 per 100 ml. or less.

The practical value of plant curves in sewage chlorination is limited by the range of the confidence limits, since curves with a narrow range require the maintenance of lower chlorine residuals to insure that a given percentage of M.P.N. values are below the standard value of M.P.N. The inaccuracies in the tests for residual chlorine and the M.P.N. are factors that affect the range of confidence limits. Any factor which tends to make the position of a data point unreliable will increase

the range in the confidence limits. Therefore, those factors not evaluated in the original curve (such as B.O.D. or suspended solids concentration) will probably contribute to an increased range in confidence limits.

Some estimate of the differences in the range of confidence limits can be obtained by an examination of the variance values in Table I, which are approximately proportional to the range of the confidence limits. Individual variance values range from a low of 0.131 to a high of 0.446.

Discussion

The curves and data for the individual plants were scrutinized to determine whether any pattern of chlorination results could be established for the totality of plants and to determine whether plants with high removal efficiencies are identified by mortality curves which differ radically from the curves characteristic of plants with low efficiencies. The establishment of this relationship would greatly enhance the practical value of the method described here, since it would then be possible not only to extrapolate results for an individual plant, but also to forecast mortality curves for contemplated plants.

Statistical analysis of all the plant data showed that an exceptionally high correlation existed between the M.P.N. at 0 residual (the intercept value) and the rate of kill (the slope). There was less than one chance in 1,000 that the correlation obtained occurred through the agency of chance alone. Since low numbers of bacteria in the effluent prior to chlorination generally indicate a high degree of treatment, some relationship between the type of curve and the degree of treatment, as evidenced by the B.O.D. or the suspended solids removal, appeared probable. However, the correlations were not significant for the following relationships:

1. M.P.N. at 0 residual *vs.* % B.O.D. removal.
2. M.P.N. at 0 residual *vs.* % S.S. removal.
3. M.P.N. at 0 residual *vs.* p.p.m. B.O.D. in effluent.
4. M.P.N. at 0 residual *vs.* p.p.m. S.S. in effluent.
5. Rate of kill *vs.* % B.O.D. removal.
6. Rate of kill *vs.* % S.S. removal.
7. Rate of kill *vs.* p.p.m. B.O.D. in effluent.
8. Rate of kill *vs.* p.p.m. S.S. in effluent.

This lack of correlation demonstrates that if relationships of the type discussed do exist, more precise and accurate data than those available for this analysis are necessary.

Since considerable kills have been obtained with sub-zero residuals of chlorine (6), the possibility of describing the full course of bacterial kill by the use of an M.P.N.-dosage curve, rather than an M.P.N.-residual curve, was investigated. When a curve of the type represented by Eq. 1 was utilized in the description of M.P.N. *vs.* dosage for an individual plant, an inconsistency was noted. The curve required that the M.P.N. be extremely large at some value of the chlorine dosage, or, more exactly, the M.P.N. approaches infinity at some point, since the curve is discontinuous. This is at variance with the field data.

The failure of a curve of the type of Eq. 1 to fit observed data when chlorine dosages are used for the variable R, exhibits the inherent weakness of empirical curve fitting. The choice of the type of curve is dependent to some extent on the personal likes and dislikes of the analyzer. Hence, it would be presumptuous to assume that a curve selected by personal inclination demonstrates a causal relationship. The personal element has a varying degree of importance, and in instances where the data are subject to large variations, such as the sewage treatment plant data analyzed in this paper, the role of the individual is emphasized

and the scientific ideal of objectivity is difficult of realization.

The need for an inclusive theory to reduce the importance of subjective decisions, and in a larger sense to develop that aspect of sanitary science dealt with herein, is readily apparent. Development is often contingent upon comprehension and it is hoped that by increasing understanding of the problem by some small measure, the possibility of developments in the chlorination of sewage will be enhanced. A theory of bactericidal action developed by the authors will be presented in a succeeding paper.

Summary and Conclusions

Treatment plant data of installations under the jurisdiction of the Interstate Sanitation Commission have been analyzed for the relationship between residual chlorine and the M.P.N. of coliform organisms.

A relationship exists at any given plant that can be described by a curve of the type

$$\frac{1}{\log \text{M.P.N.}} = a + b\,R$$

in which M.P.N. is the most probable number of coliform organisms, R is the total chlorine residual, and a and b are constants.

Individual curves, with the additional use of confidence limits, can be used to estimate the chlorine residual required to maintain any given M.P.N. within the required degree of accuracy.

Considering the plants as a whole, a relationship is demonstrated between values of a, equal to 1/log M.P.N. at 0 residual, and b, which is directly proportional to the killing rate. Apparently plants characterized by a low M.P.N. at 0 residual tend to have a low killing rate.

The failure of the curve previously described to satisfactorily describe the data at a given plant, when chlorine dosages are substituted for residuals, indicates the need for a greater theoretical understanding of the bactericidal effects of sewage chlorination.

Acknowledgment

Morris B. Smith, Meyer Deitch, Marshall E. Ferguson, Fred W. Gross, and Robert Pedersen, all staff members of the Interstate Sanitation Commission, assisted in the field analyses, aided in the required calculations, critically analyzed the subject matter of this paper, and provided the mental stimulation which materially aided this study.

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OXIDATION-REDUCTION POTENTIAL OF CHLORINATED SEWAGE

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Numerous determinations have been made of the oxidation-reduction potential of sewage at various stages of its treatment (1) (2) (3) (4) (5) (6). The authors, however, know of no published data giving the oxidation-reduction potential of sewage and sewage effluent treated with different amounts of chlorine.

Experimental Procedure

To throw light on this problem several series of laboratory tests were made, consisting of chlorinating raw sewage and the effluent from humus tanks following trickling filters at the Back River sewage treatment works, which serves Baltimore, Md. Three of these groups of tests have been selected for discussion.

In the first group of tests the raw sewage and the humus tank effluent were filtered through non-absorbent cotton to remove large suspended matter. Gaseous chlorine dissolved in tap water was then added to the samples in amounts ranging from 5 to 250 p.p.m. The E_h, pH, and NH_3 of the sewage and the effluent were determined before and after the addition of chlorine. Furthermore, residual chlorine was determined after holding the samples for ½, 1, and 24 hr. Determinations of E_h were made in triplicate with a Beckman hydrogen ion meter. Chlorine residuals were determined by the acid starch-iodide method in the first group of tests, by both the acid and the neutral starch-iodide method in the second group of tests and by the neutral starch-iodide method in the third group of tests. As the acid starch-iodide method gave chlorine residuals that were considered higher than they should have been, they were not used in reporting the second group of tests.

Results Obtained

The results obtained are shown in Figures 1, 2 and 3. Figure 1 indicates the amount of residual chlorine and the E_h of the raw sewage corresponding to various chlorine dosages. The "hump" and the "break" in the chlorine residual curve occurred with chlorine applications of 120 and 130 p.p.m., respectively. The chlorine residual after 1 hr. was only slightly less than after 0.5 hr. However, there was considerable reduction in residual chlorine at the end of 24 hr. In general, this reduction was somewhat greater to the left of the "break" than to the right of it.

There was a sharp increase in the E_h potential of the sewage from 455 to 1,305 millivolts as the chlorine dosage was increased to 50 p.p.m. As the dosage exceeded 50 p.p.m., the increase in the E_h potential was much less, increasing from 1,305 to 1,380 mv. as the dosage was increased to 250 p.p.m. There was little difference in the E_h of sewage 30 and 60 min. after the application of chlorine, and even holding the sewage for 24 hr. did not greatly reduce the E_h potential, particularly when large dosages were used. For example, when 100 p.p.m. of chlorine were used, the E_h of the sewage dropped from 1,359 to 1,335 mv.

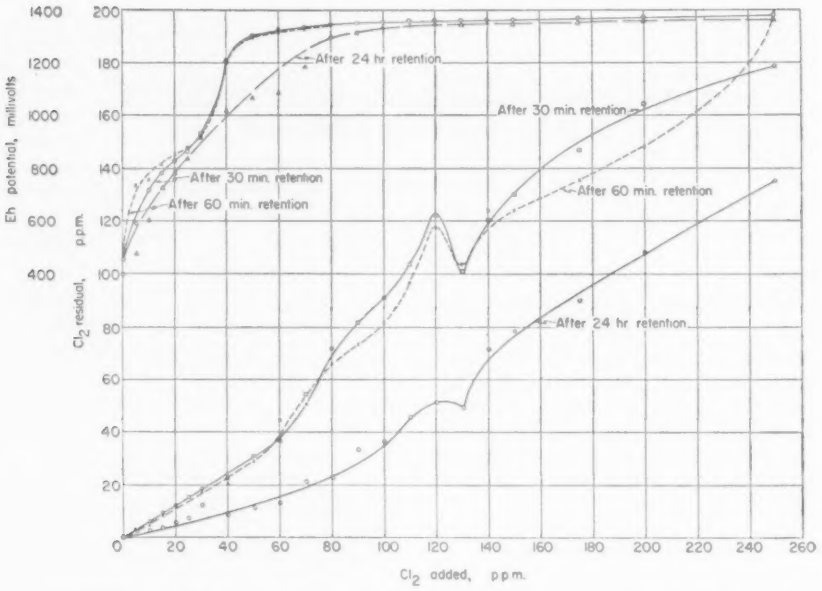

FIGURE 1.—Chlorine residual and oxidation-reduction potential of chlorinated raw sewage.

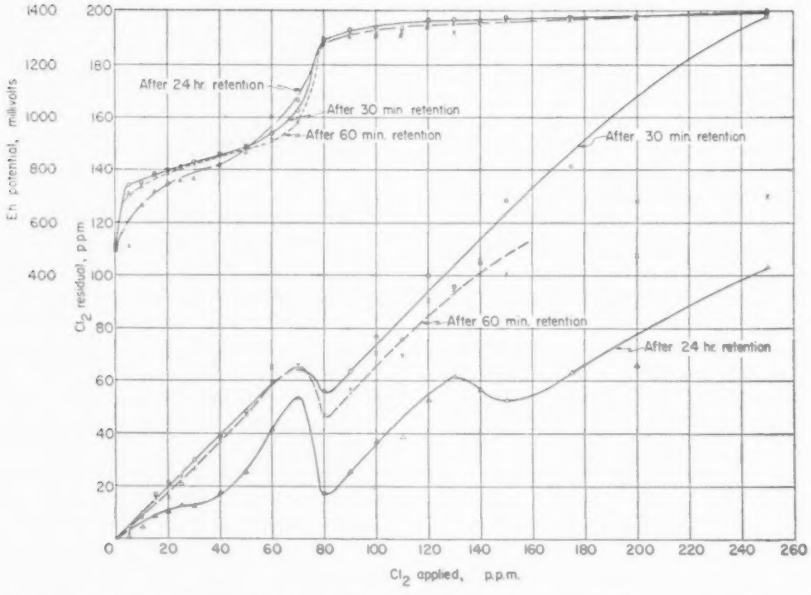

FIGURE 2.—Chlorine residual and oxidation-reduction potential of chlorinated humus tank effluent.

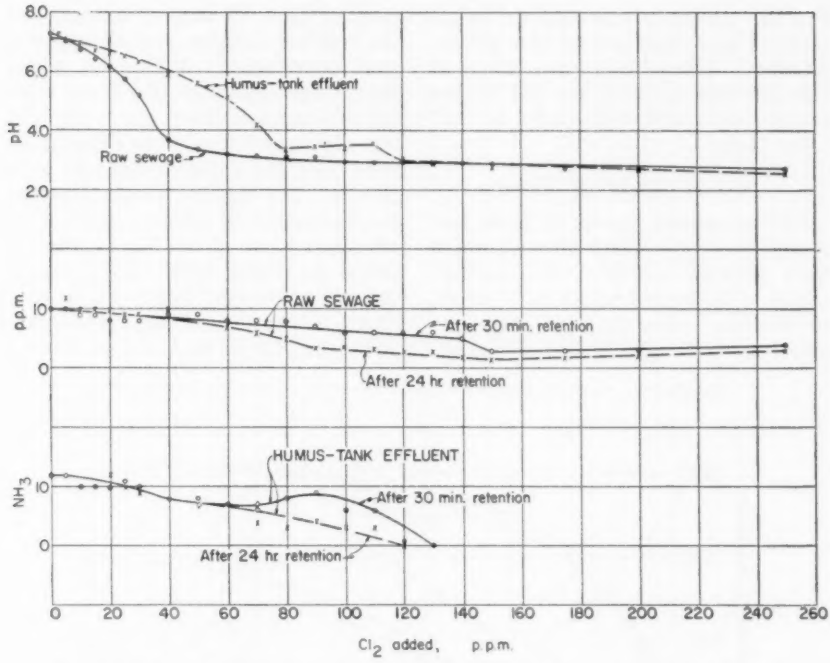

FIGURE 3.—Ammonia content and pH of chlorinated raw sewage and humus tank effluent.

Figure 2 shows the chlorine residual and E_h potential of chlorinated humus tank effluent after 0.5, 1, and 24 hr. The "hump" in the chlorine residual curve was much less than was the case when raw sewage was chlorinated. The "hump" occurred with an application of 70 p.p.m. of chlorine. With this dosage the residual was 64.6 p.p.m. after 0.5 hr. and 53.3 p.p.m. after 24 hr. The "break" occurred with a dosage of 80 p.p.m. The "hump" and the "break point" in the chlorine residual curve occurred with much smaller chlorine dosages when humus tank effluent was chlorinated than when raw sewage was chlorinated, the reason being that the humus tank effluent was considerably weaker than the raw sewage.

The E_h of the chlorinated humus tank effluent increased rapidly from 499 to 1,295 mv. with chlorine applications increasing from 0 to 80 p.p.m. As the dosages were increased from 80 to 250 p.p.m., the E_h potential increased at a much lower rate to 1,394 mv.

Figure 3 indicates the decrease in ammonia and pH of the raw sewage and the humus tank effluent with applications of chlorine ranging from 0 to 250 p.p.m. Ammonia destruction was more complete in the case of the humus tank effluent. Holding either the raw sewage or the humus tank effluent resulted in a further decrease in ammonia.

There was a comparatively rapid decrease in pH with chlorine applications up to 40 p.p.m. in the case of raw sewage, and up to 80 p.p.m. in the case of humus tank effluent. With greater applications the reduction in pH was comparatively small. For example, increasing the chlorine applied to the raw sewage from 60 to 250 p.p.m. resulted in a pH reduction from 3.22

to 2.72. Holding the sewage for 24 hr. resulted in a small but further pH reduction. When 50 p.p.m. dosage of chlorine was applied, the pH of the sewage decreased from 3.36 to 3.10 after 24 hr.

Second Group of Tests

In the second group of tests raw sewage and humus tank effluent, which were filtered through non-absorbent cotton, were treated with 2 to 25 p.p.m. of chlorine. After the raw sewage was chlorinated, it was held for periods varying from 30 min. to 10 days and the residual chlorine and E_h potential were determined. Figures 4 and 5 give the results obtained. When treating raw sewage, there was a straight-line variation between the chlorine applied and the chlorine residual after 30 min. The chlorine residual became less the longer the contact time. With an application of 25 p.p.m. the residual decreased from 16.4 p.p.m. at the end of 30 min. to 8.8 p.p.m. after 24 hr., a reduction of slightly less than 50 per cent. At the end of 10 days

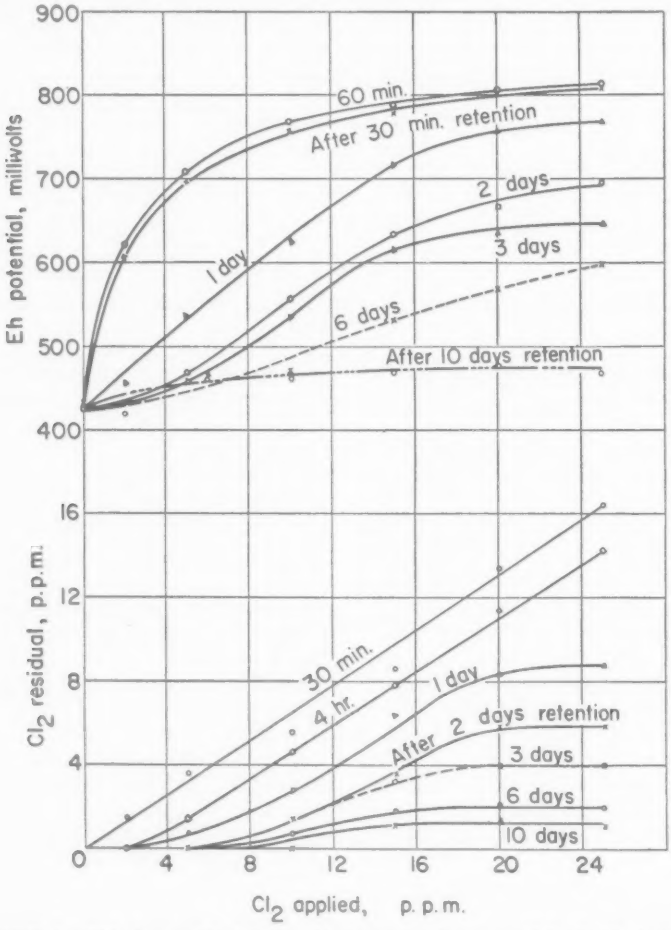

FIGURE 4.—Chlorine residual and oxidation-reduction potential of chlorinated raw sewage (retention, 30 min. to 10 days).

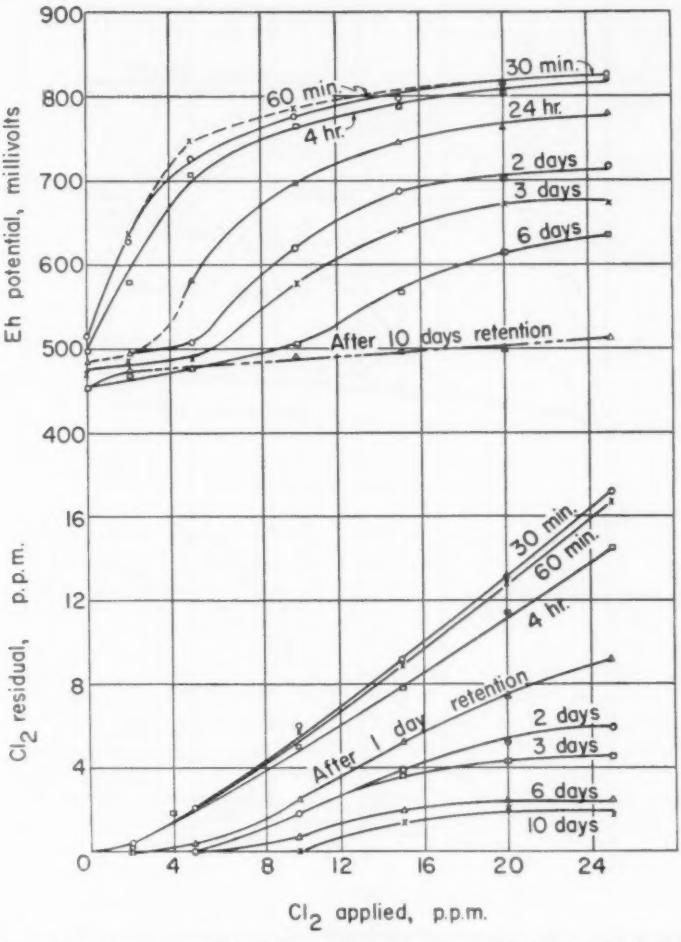

FIGURE 5.—Chlorine residual and oxidation-reduction potential of chlorinated humus tank effluent (retention, 30 min. to 10 days).

the residual was 1.1 p.p.m., which was equivalent to a reduction of 93 per cent.

The E_h potential of the sewage increased with increasing applications of chlorine and decreased as the contact time increased. With a chlorine application of 25 p.p.m. the E_h potential decreased from 810 to 769 mv. after 24 hr., and to 468 mv. after 10 days.

Figure 5 gives the chlorine residual and E_h potential of humus tank effluent treated with 2 to 25 p.p.m. of chlorine. The results are only slightly different from those when raw sewage was chlorinated. The principal difference, which was not pronounced, was that the E_h potentials of the humus tank effluent, both before and after chlorination, were somewhat higher than those of the raw sewage.

Third Group of Tests

In the third group of tests a sample of raw sewage was screened to give it a more uniform character, then divided

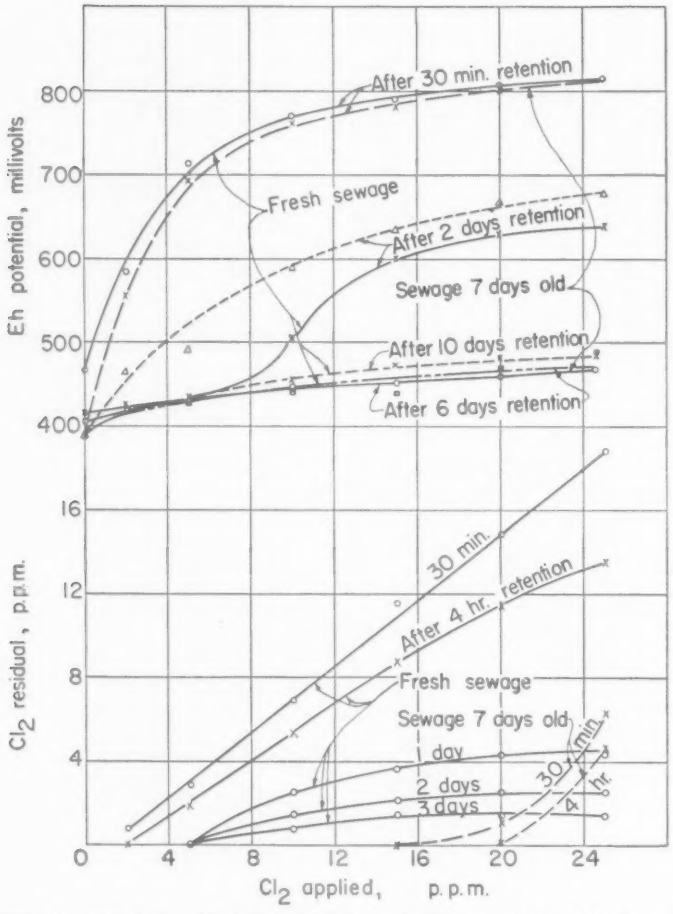

FIGURE 6.—Chlorine residual and oxidation-reduction potential of fresh and 7-day-old sewage.

into two portions and treated with 2 to 25 p.p.m. of chlorine. Chlorine residuals and E_h potentials were determined at intervals varying from 30 min. to 10 days. The difference between the two portions of sewage was their age. One sample was chlorinated immediately after it was collected, and the other was stored at room temperature for 7 days before it was chlorinated.

The results are given in Figure 6. The fresh sewage, treated with 25 p.p.m. of chlorine, had a chlorine residual of 18.8 p.p.m. after 30 min. and 13.5 p.p.m. after 4 hr. The residual continued to decrease with time and after 6 days was 0.35 p.p.m.

That the age of sewage has a marked effect on chlorine residuals is evidenced by the results obtained when the 7-day old sewage was chlorinated. It was necessary to apply 20 p.p.m. to get any residual. When the dosage was 25 p.p.m. the residual was 6.20 p.p.m. after a 30-min. contact period, and 1.40 p.p.m. after 2 days.

Although the sewage that was 7 days

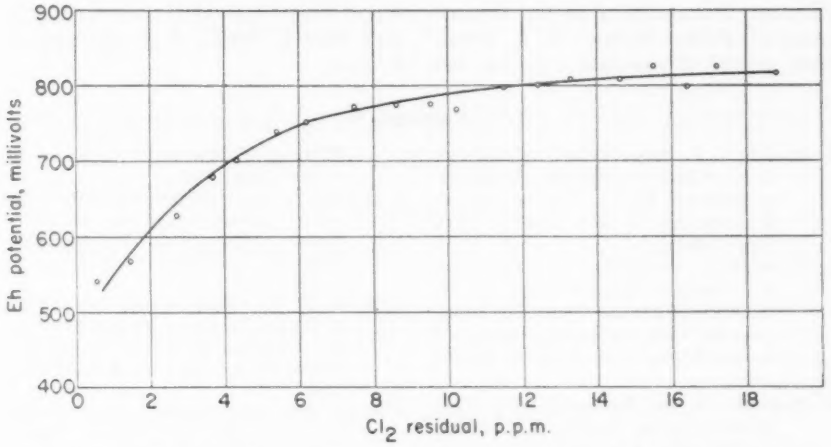

FIGURE 7.—Relation between oxidation-reduction potential and chlorine residual in chlorinated sewage.

old had a much lower chlorine residual than the fresh sewage for each application of chlorine, there was little difference in the E_h potentials of the two sewages.

The general relationship between the chlorine residual and the E_h potential of chlorinated sewage is given in Figure 7. The residuals as plotted result from the application of 2 to 25 p.p.m. of chlorine to raw sewage and humus tank effluent after time periods varying from 30 min. to 10 days. Each E_h potential shown is the average of all the values which fall within a narrow chlorine residual range. The curve is based on 170 groups of determinations, which were made when chlorinating six different samples of raw sewage, one of which was 7 days old, and two samples of humus tank effluent. It is apparent that, in general, a definite relationship existed between the E_h potential of the sewage and the chlorine residual.

Discussion and Conclusions

1. As was to be expected, the "hump" and the "break point" in the chlorine residual curves occurred with higher dosages of chlorine when applied to raw sewage than when applied to humus tank effluent.

2. When chlorinating both raw sewage and humus tank effluent, the E_h potential curves approached an asymptote with a value slightly less than 1,400 mv. With a chlorine dosage of 250 p.p.m. this potential changed but little up to a holding time of 24 hr.

3. When 25 p.p.m. of chlorine was applied to raw sewage, a residual was observed after 6 days in one case and 10 days in another.

4. Chlorinating stale sewage resulted in reduced chlorine residuals. However, there was little difference in the E_h potential of fresh and stale sewage after chlorination. There was a slow decrease in the E_h potential of the chlorinated sewage with time. Even after 10 days, however, the sewage had a higher potential than fresh unchlorinated sewage.

Acknowledgments

The Back River sewage treatment works, where the foregoing experiments were conducted, is under the general direction of P. L. Holland, director, Department of Public Works, and John J. Hunt, sewerage engineer. Dr. Abel

Wolman is consultant to the Department of Public Works. R. J. Trautman, principal associate engineer, has direct supervision of the sewage works, and Paul L. Smith is plant superintendent.

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6. Hood, J. W., and Rohlich, G. A., "Oxidation-Reduction Potentials in Sewage Treatment." *Water and Sewage Wks.*, **96**, 9, 352 (1949).

EARLE B. PHELPS DIES

Earle B. Phelps, Professor of Public Health Engineering at the University of Florida, died at his home in Gainesville, Fla., on May 29, 1953. He was recognized as a pioneer investigator and an authority on sewage chemistry, stream sanitation, and public health engineering.

After graduation from Massachusetts Institute of Technology in 1899, he became associated with the Lawrence Experiment Station of the Massachusetts State Board of Health. Thereafter he helped organize and conduct well-known studies by the U. S. Public Health Service on the pollution and self-purification of the Ohio River and served as consultant to several cities and states in various capacities. He had been Associate Professor at M.I.T.; Professor of Chemistry at the Hygienic Laboratory of the U.S.P.H.S.; Consulting Sanitary Engineer for the International Joint Commission on United States-Canadian Waterways; and Visiting Professor at the University of Puerto Rico. Prior to joining the faculty at the University of Florida he had retired as Professor Emeritus of Sanitary Science, School of Public Health, College of Physicians and Surgeons, Columbia University.

Professor Phelps was the author of several texts on stream sanitation and public health engineering, as well as many articles in the technical press.

A member of the New York Sewage and Industrial Wastes Association since 1929, Professor Phelps was a member of the Federation's original "Committee of 100," and served as the New York Association representative on the Board of Control from 1932 to 1937, during which period he was a member of the Research Committee. For the past several years he also had been an Honorary Member of the Florida Sewage and Industrial Wastes Association.

MEASUREMENTS OF THE RESPIRATORY ACTIVITY OF ACTIVATED SLUDGE *

By David B. Smith

Associate Professor of Civil Engineering, University of Florida, Gainesville, Fla.

Considerable study has been devoted to the use of activated sludge oxygen requirements as a measure of the condition of the biological system in activated sludge operations (2) (3) (4) (6) (7) (8) (9). Such studies have demonstrated that the rate of oxygen utilization by activated sludge is influenced by the sludge concentration, temperature, sludge acclimatization, light, pH, and certain organic and inorganic chemicals.

At least one direct and two indirect methods are available for measuring the respiratory activity of activated sludge. The direct method relies upon a measurement of the rate of absorption of gaseous oxygen by the sludge. The indirect methods are based upon either a measurement of the rate of decrease in the oxygen demand of the sludge or a measurement of the rate of carbon dioxide production by the sludge.

In the past, the direct method has been preferred by most workers in this field of research. "Standard Methods" (1) describes an apparatus for the determination of the oxygen demand of activated sludge based upon the direct sorption principle, but a majority of the work in this direction has been conducted through the use of Warburg or Sierp manometers. All are based upon batch operation.

In a previous paper (10) the author has described an experimental activated sludge unit that was designed and operated utilizing the continuous-flow principle. This unit permitted investigation of the activated sludge treatment process under conditions similar to those encountered in plant-scale operation. However, measurements of the oxygen uptake of the activated sludge in a continuous-flow system presented difficulties in that the aeration tank could not be enclosed satisfactorily. Consequently, an indirect method of measurement was developed in which enclosure of the system was not necessitated. This method is based upon an estimation of the aeration chamber reaeration characteristics and permits an evaluation of the biological oxygen uptake of activated sludge *in situ*.

It is the purpose of this paper to present the theory of a new method of oxygen utilization measurement and to present the results of measurements of the respiratory activity of an activated sludge.

Theory of Oxygen Utilization

In activated sludge systems there are normally two sources from which oxygen is derived. These are the dissolved oxygen content of the inflowing sewage and the oxygen introduced into the liquor by aeration. Using these facts and assuming steady conditions, Prof. H. A. Thomas, Jr., at Harvard, has originated a method whereby the rate of oxygen uptake by activated sludge may be estimated as a function of the rate of reaeration in the aeration tank.

Figure 1 is a diagrammatic representation of the aeration tank of an

* Presented at 1953 Annual Meeting, New York Sewage and Industrial Wastes Assn.; New York, N. Y.; Jan. 22–23, 1953.

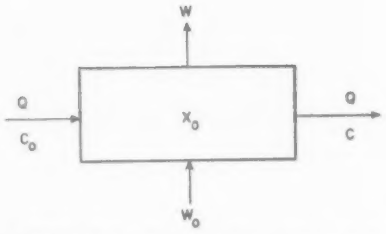

FIGURE 1.—Steady-state conditions for biological oxygen uptake in an aeration tank.

activated sludge system. When steady-state conditions prevail,

Q = the rate of sewage inflow, in liters per minute;
C_o = the oxygen concentration in the inflow, in milligrams per liter;
C = the oxygen concentration in the outflow, in milligrams per liter;
W_o = the rate of oxygen entering the tank in the air supply, in milligrams per minute;
W = the rate of oxygen leaving the tank in the air supply, in milligrams per minute; and
X_o = the rate of biological uptake of oxygen, in milligrams per minute.

Consequently, at equilibrium

$$X_o = Q\,(C_o - C) + W_o - W \quad (1)$$

However, the oxygen derived from the air supply may be stated in terms of the contact tank reaeration constant. This constant is determined by the physical characteristics of the tank and its aeration device. Since the rate at which oxygen is deducted from the air supply is a function of the oxygen deficit, this rate may be expressed as

$$W_o - W = K\,A\,(C_s - C) \quad (2)$$

in which

$K\,A$ = the product, in liters per minute, of the reaeration constant and the air-liquid interfacial area resulting from a given W_o; and

C_s = the oxygen concentration in the liquid at saturation, in milligrams per liter.

If Eq. 1 and 2 are combined,

$$X_o = Q\,(C_o - C) + K\,A\,(C_s - C) \quad (3)$$

If, now, the oxygen concentration in the inflowing sewage, C_o, is changed to a second concentration, C_o', and if the biological uptake is uninfluenced by alterations in the value of C, a second equation of steady state results. This relationship is

$$X_o = Q\,(C_o' - C') + K\,A\,(C_s - C') \quad (4)$$

Solution of Eqs. 3 and 4 for $K\,A$ gives

$$K\,A = \frac{Q\,(C_o' - C' - C_o + C)}{C' - C} \quad (5)$$

The five terms on the right-hand side of Eq. 5 can be determined experimentally with relative ease, provided the air supply is held constant. A suitable method for altering the value of C_o over a wide range is also necessary. Once a series of $K\,A$ values, together with the corresponding W_o values, has been determined, it is possible to relate these two variables by means of a calibration curve. Eq. 3 may then be used to compute the rate of oxygen uptake.

Detention Characteristics of Contact Tank

An approximation necessary to the proper usage of Eqs. 3 and 5 is the assumption that the oxygen tension in the aerated liquor is uniform throughout the tank. This assumption implies perfect mixing. Although this condition cannot be attained, it is still possible to obtain valid results if near-perfect mixing exists in the tank.

The detention characteristics of the tank were determined by means of salt flow-through tests. KCl was the salt employed, and its concentration was determined conductometrically. Two tests were made—one without

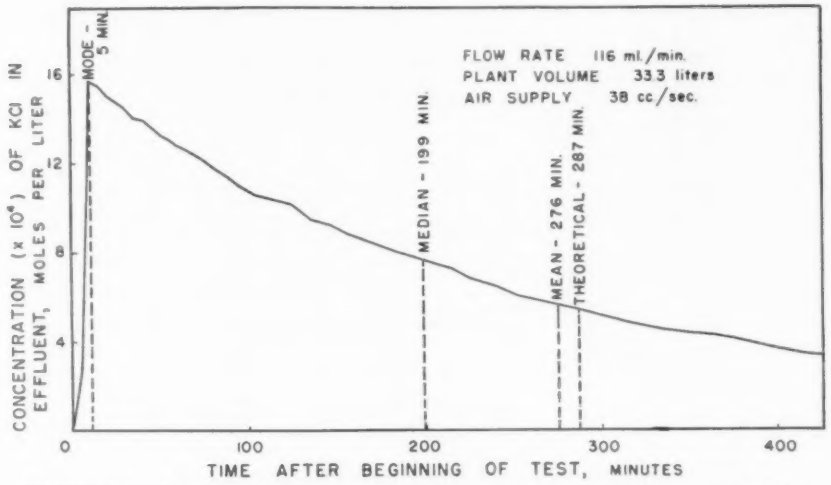
FLOW RATE 116 ml./min.
PLANT VOLUME 33.3 liters
AIR SUPPLY 38 cc./sec.
MODE - 5 MIN.
MEDIAN - 199 MIN.
MEAN - 276 MIN.
THEORETICAL - 287 MIN.
CONCENTRATION (x 10⁴) OF KCl IN EFFLUENT, MOLES PER LITER
TIME AFTER BEGINNING OF TEST, MINUTES

FIGURE 2.—Salt flow-through test on contact aeration tank without contact plates.

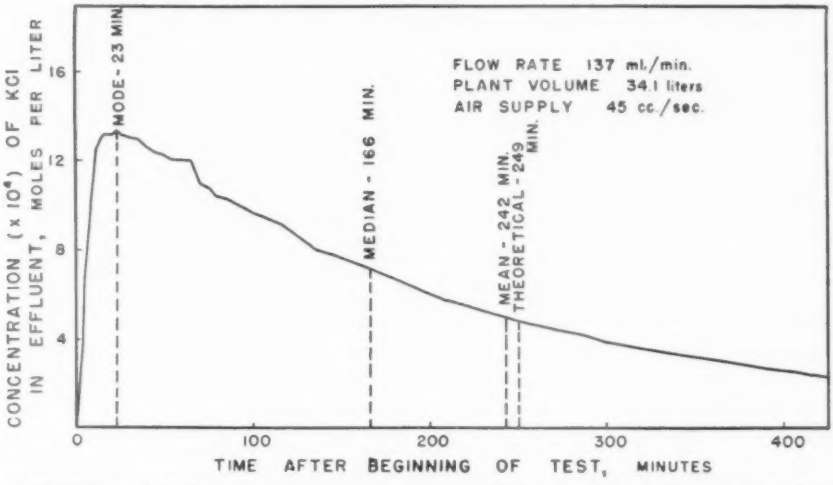
FLOW RATE 137 ml./min.
PLANT VOLUME 34.1 liters
AIR SUPPLY 45 cc./sec.
MODE - 23 MIN.
MEDIAN - 166 MIN.
MEAN - 242 MIN.
THEORETICAL - 249 MIN.
CONCENTRATION (x 10⁴) OF KCl IN EFFLUENT, MOLES PER LITER
TIME AFTER BEGINNING OF TEST, MINUTES

FIGURE 3.—Salt flow-through test on contact aeration tank with 10 glass contact plates in position.

contact plates and one with 10 glass contact plates in position. The results are shown in Figures 2 and 3. In both tests the early occurrence of the mode and the subsequent logarithmic decrease in the salt concentration indicated near-perfect mixing. Since wire screens were used for contact surfaces during the oxygen-uptake measurements, the detention characteristics probably were similar to those found when no contact plates were used.

Laboratory Studies

Except for the determinations of the contact tank reaeration traits, the data used in this study were obtained in the manner described in a previous paper (10).

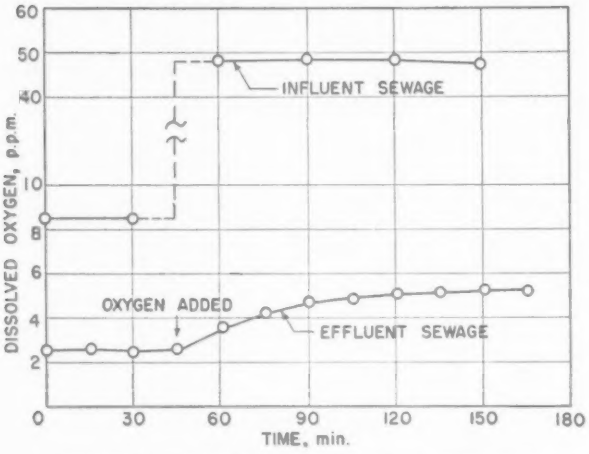

FIGURE 4.—Results of one reaeration measurement.

Reaeration Studies

The reaeration characteristics of the contact tank were measured while a fully-matured activated sludge existed on the contact surfaces. It was found that a practical method of altering the oxygen content of the inflowing sewage was to subject it to an atmosphere of commercially pure oxygen. The oxygenation equipment and method of Okun (5) were used for this purpose.

During the determination of each $K\,A$ value a predetermined rate of air was introduced into the contact tank. The oxygen supply remained off until the system reached equilibrium as measured by dissolved oxygen determinations on the inflowing and outflowing sewage. The oxygen supply was then turned on, and the changes in oxygen concentrations observed until the system again reached equilibrium. Figure 4 presents the data of one series of determinations.

Eight runs were made, each at a different rate of air supply, and the corresponding $K\,A$ values were computed. The resulting calibration curve is shown in Figure 5.

A value for C_o was obtained from the results of dissolved oxygen determinations on samples of the synthetic sewage taken at the pump effluent line. Fourteen such measurements indicated that the oxygen content of the inflowing sewage was 12.18 ± 0.06 p.p.m.

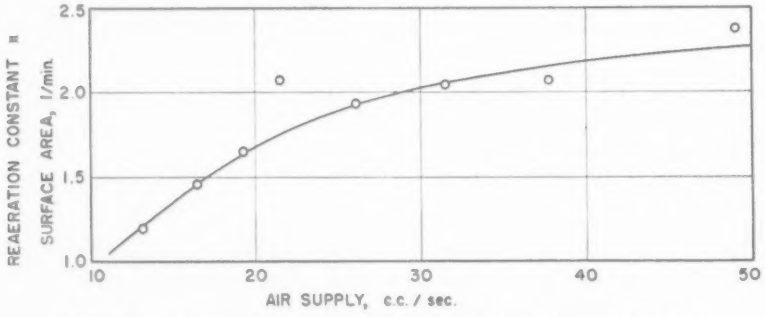

FIGURE 5.—Contact plant reaeration values at various air supplies.

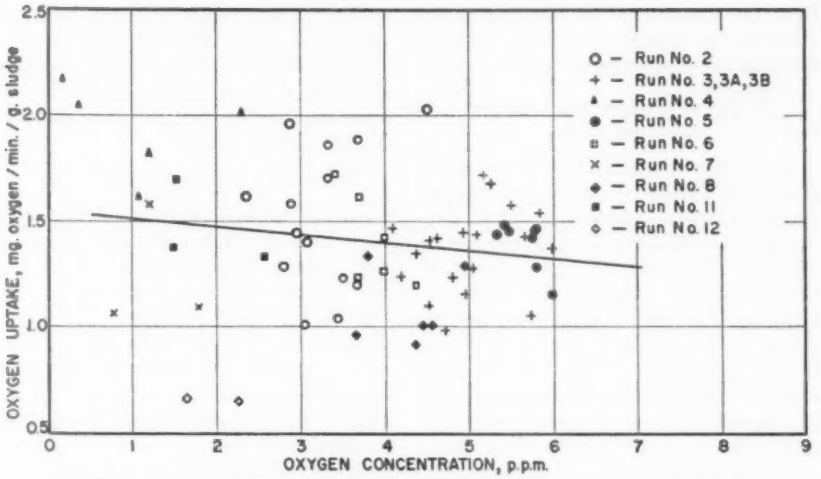
OXYGEN UPTAKE, mg. oxygen / min. / g. sludge
OXYGEN CONCENTRATION, p.p.m.
O — Run No. 2
+ — Run No. 3,3A,3B
▲ — Run No. 4
● — Run No. 5
□ — Run No. 6
× — Run No. 7
◆ — Run No. 8
■ — Run No. 11
◇ — Run No. 12

FIGURE 6.—Relationship between oxygen concentration and oxygen uptake.

C_s was assumed to be equal to the oxygen saturation value of water at 25° C. and standard pressure. As a result, subsequent computations of the oxygen uptake were made using

$$X = Q\,(12.18 - C) + K\,A\,(8.35 - C) \ldots (6)$$

It was assumed that the equilibrium conditions described by Eq. 1 prevailed just prior to the daily plate removal operation. At this time the rate of air supply and the oxygen concentration in the effluent were measured. Computations for the rate of sewage flow completed the data necessary for the application of Eq. 6.

Each oxygen uptake value thus obtained was reduced to a basic unit in terms of the weight of oxygen uptake per minute per gram of dry sludge.

Analytical Determinations

All analytical determinations were made according to the procedures given in "Standard Methods" (1) except

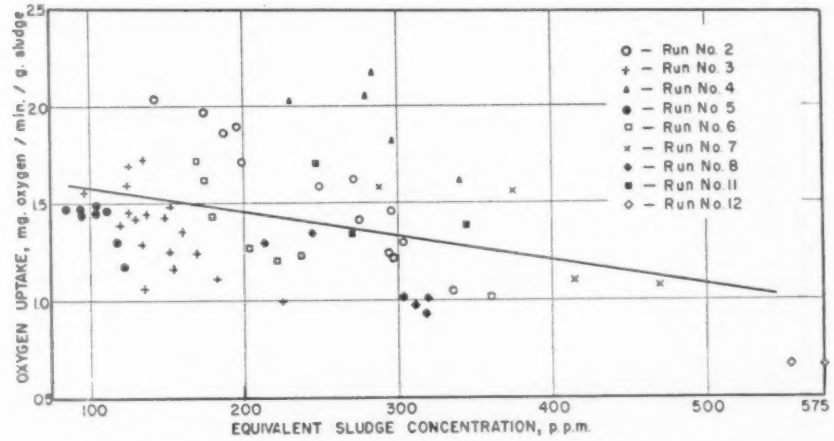
OXYGEN UPTAKE, mg. oxygen / min. / g. sludge
EQUIVALENT SLUDGE CONCENTRATION, p.p.m.
O — Run No. 2
+ — Run No. 3
▲ — Run No. 4
● — Run No. 5
□ — Run No. 6
× — Run No. 7
◆ — Run No. 8
■ — Run No. 11
◇ — Run No. 12

FIGURE 7.—Relationship between sludge concentration and oxygen uptake.

that the quantities of reagents were doubled in dosing dissolved oxygen samples of high oxygen concentration.

Oxygen Uptake *vs.* Oxygen Concentration

A scatter diagram for 66 observations of the effect of oxygen concentration on oxygen uptake is shown in Figure 6. A statistical analysis indicates that for these data the line of best fit has a slope of − 0.038. It was found, however, that such a slope may be expected to occur 85 per cent of the time if the true slope of the line is zero. Consequently, no significant trend can be shown between oxygen concentration and oxygen uptake from these data. It is notable that this conclusion is evident although the range of oxygen concentration extended from 0.2 to 6 p.p.m. This finding validates the assumption, used in the derivation of Eq. 4, that the biological oxygen uptake is uninfluenced by alterations in the dissolved oxygen concentration.

Oxygen Uptake *vs.* Sludge Concentration

The relationship between the rate of oxygen uptake and the equivalent sludge concentration is shown in Figure 7. The sludge concentration was computed from the assumption that the sludge was uniformly distributed throughout the mixed liquor. The equation of the straight line of best fit was found to be

$$Y = 1.69 - 0.00124X \ldots . \quad (7)$$

where X is the equivalent sludge concentration in p.p.m., and Y is the oxygen uptake in milligrams of oxygen per minute per gram of sludge. At the 95 per cent confidence level the slope of the line lies between − 0.0019 and − 0.0006. Consequently, a significant decrease in the activity of the sludge with increasing sludge concentration is evident.

It is reasoned that the individual floc masses contain centers of inactivity, and that as the sludge concentration on the contact plates increases, a larger percentage of the sludge becomes dormant. The reason for this trend may be explained by a slow rate of diffusion of food particles through the outer layers of the sludge, thus creating a deficit of food in the deeper layers of the sludge film. This effect was evident in the experimental unit because the thickness of sludge on the contact plates varied within wide limits.

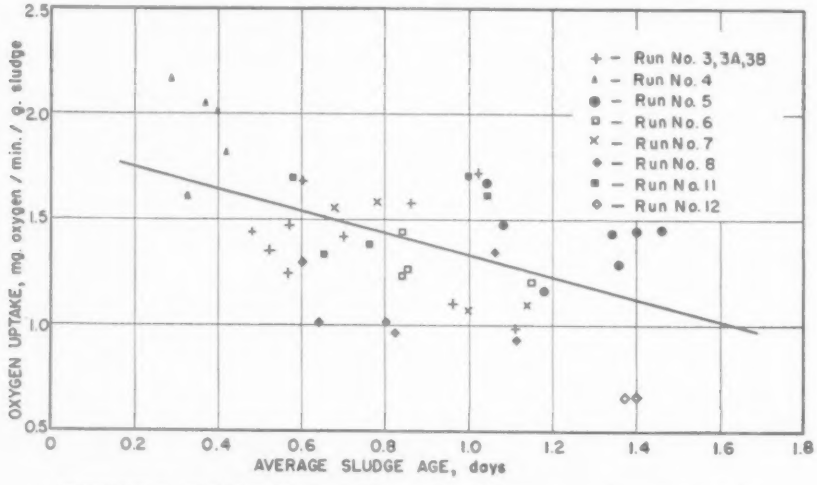

FIGURE 8.—Relationship between average sludge age and oxygen uptake.

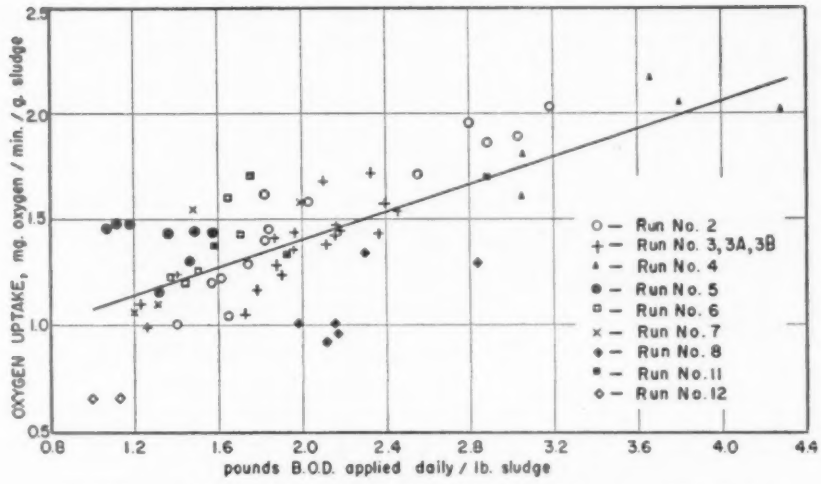

FIGURE 9.—Relationship between applied B.O.D. load and oxygen uptake.

Oxygen Uptake *vs.* Sludge Age

It is a well-known fact that the growth activity of a culture of bacteria decreases with increase in cultural age. It may be reasoned that since the oxygen consuming ability of an activated sludge depends primarily on the presence of bacteria, the effect of age on an activated sludge would parallel that on a bacterial culture. This hypothesis is verified by Figure 8.

The average sludge age was computed as the weight of sludge in the contact aerator at the end of each day, divided by the weight of solids produced in and added to the system per day. The straight line of best fit is

$$Y = 1.85 - 0.522X \ldots\ldots (8)$$

in which X is the average sludge age in days, and Y is the oxygen uptake in the units previously given. At the 95 per cent confidence level, the indicated slope lies between -0.79 and -0.26. As a result, a highly significant decrease in oxygen uptake occurs with increasing sludge age. However, it is not to be expected that this relationship is truly linear. The data would probably assume the shape of a logarithmic die-away curve if they were extended to sludge ages greater than were found in these experiments.

Oxygen Uptake *vs.* B.O.D. Loading and Removal

It was found that definite correlation existed between the rate at which oxygen was utilized by activated sludge and the rate at which food was applied to the sludge. The trend is indicated by Figure 9, the straight line of best fit being

$$Y = 0.75 + 0.331X \ldots\ldots (9)$$

in which X is the pounds of B.O.D. applied daily per pound of sludge, and Y is the oxygen uptake. The 95 per cent confidence limits for the indicated slope are 0.26 and 0.41.

A similar relation exists between the oxygen uptake and the amount of B.O.D. removed from the substrate (Figure 10), the straight line of best fit being

$$Y = 0.55 + 0.675X \ldots\ldots (10)$$

In Eq. 10, X is the pounds of B.O.D. removed daily per pound of sludge, and Y is the oxygen uptake. The significance of this trend is shown by the 95

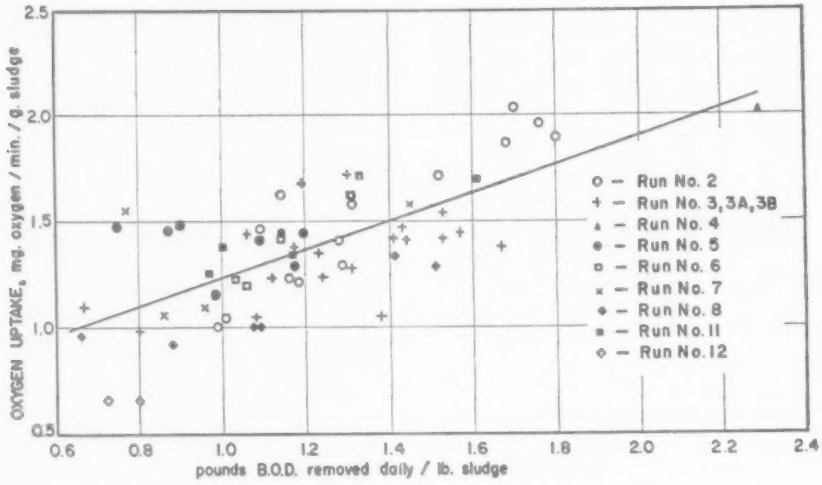

FIGURE 10.—Relationship between oxygen uptake and B.O.D. removed from the substrate.

per cent confidence limits of the slope, which are 0.51 and 0.84.

It is reasonable to expect that biological activity will temporarily increase with increased food supply. However, the presence of additional nutrient material would be expected to promote the development of sufficient sludge so that at equilibrium the unit activity would have a constant value. Such is not the case. Apparently, the bacterial cells adjust themselves to existing food conditions and are more dormant in cases of low food supply than when ample food is available.

Comparison with Manometric Measurements

For purposes of comparison, the rate of oxygen uptake by two catch samples of sludge was measured using a Warburg apparatus. The suspended solids concentrations of the samples were 4,110 and 2,690 p.p.m. These suspended solids consisted of about 80 per cent volatile solids in both cases. The constant-temperature bath was held at 25° C., which corresponded to the temperature at which the sludge had been developed. The measurements were started about 1 hr. after the sludge samples were collected, and observations were taken over a 2-hr. period on 1-, 2-, and 3-ml. volumes of each sample. The average oxygen uptakes were found to be 0.35 and 0.27 mg. of oxygen per minute per gram of sludge, respectively, for the low-concentration and high-concentration sludges.

These rates of oxygen uptake are considerably less than those measured by the reaeration method. It is believed that the reaeration method gave results which are more indicative of the conditions that existed within the contact aerator. Further, the time lag between the collection of the manometric samples and the subsequent measurement of the rates of oxygen utilization would tend to decrease the activity of the sludge.

Summary and Conclusions

A new method for the indirect measurement of activated sludge oxygen utilization has been developed. This method, based on a measurement of the aeration tank reaeration characteristics, is applicable to plant-scale oper-

ations where the detention characteristics of the aeration basin indicate near-perfect mixing.

The following conclusions have been reached from studies of the steady-state oxygen requirements of aerobic, biological sludges when stabilizing a synthetic sewage:

1. Within the range of about 0.2 to 6 p.p.m. of dissolved oxygen, the average oxygen concentration of an activated sludge liquor does not significantly affect the unit rate of oxygen utilization.

2. In the contact aeration process the unit rate of oxygen utilization by activated sludge decreases with increasing concentration of sludge. The relationship found for these experiments indicates that an increase in equivalent sludge concentration from 200 to 500 p.p.m. causes a 19 per cent decrease in the rate of oxygen uptake of the sludge.

3. The oxygen uptake of an activated sludge decreases with increasing sludge age. For these experiments an increase in the average sludge age from 0.5 to 1.5 days decreased the oxygen utilization by 35 per cent.

4. An increase in the rate of B.O.D. loading of an activated sludge causes a significant increase in the rate of oxygen uptake by the sludge. A similar relationship between the rate of B.O.D. removal by an activated sludge and the rate of oxygen uptake has been demonstrated.

5. Manometric measurements of the rate of oxygen uptake by an activated sludge indicated rates considerably lower than those obtained by the reaeration method. Under the conditions of these experiments, the rates of oxygen uptake as measured by the reaeration method exhibited a 2.4- to 8.4-fold increase over the rates obtained manometrically.

Acknowledgments

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The author is grateful for the assistance and counsel of Professor Harold A. Thomas, Jr., and the faculty of the Department of Sanitary Engineering, Harvard University, and is especially grateful to his wife, who conducted a large part of the laboratory routine. A scholarship awarded by the National Institutes of Health made possible a continuation of this work.

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DISCUSSION

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The new method described by the author for measuring the biological uptake of oxygen in the activated sludge process has a number of advantages that are missing in other procedures for determination of respiratory activity. It also has certain limitations. Although a final assessment of the value of the new technique would be premature at the present time, it is pertinent to compare the method with well-known procedures entailing use of respirometers.

The scheme is predicated on the assumption of a steady state of biological activity in the sludge. In the research conducted by the author an open model aeration basin of 34-l. capacity was fed synthetic sewage of fixed concentration at a continuous rate. Sludge was wasted each day at a constant rate. After a period of several days a steady state was attained in which the daily accumulation of sludge was approximately equal to that wasted each day. The D.O. measurements necessary for evaluation of the rate of oxygen uptake (Eqs. 5 and 6) were made during this period of steady biological activity.

The only special equipment needed was an oxygen "booster" device developed by Okun (5). In pre-oxygenation the raw sewage was fed to the top of a vertical 48-in. tapered glass tube that varied in diameter from $\frac{5}{16}$ in. at the upper end to $\frac{1}{2}$ in. at the bottom, where the sewage was removed through a connection in the side. Oxygen from a steel cylinder, after passing through a pressure reduction valve and a meter, was introduced through a sintered-glass diffuser at the bottom of the booster tube. With this countercurrent flow scheme a high degree of oxygenation was attainable and a wide range of dissolved oxygen concentrations could be carried in the aeration basin.

The procedure for measurement of oxygen uptake entailed merely the determination of dissolved oxygen in the influent and effluent of the basin before and after the oxygen booster was put in operation.

It would appear that the scheme has the following advantages in the measurement of respiratory activity of biological slimes:

1. The volume of sludge and sewage under observation is large compared to sample sizes that may be investigated in the usual types of respirometers. In the latter samples from 50 to 500 ml. may be used, whereas in the study reported the volume was 34 l. and could easily have been much larger. With large test volumes, errors due to random sampling fluctuations are reduced.

2. Oxygen uptake is measured while the sludge is being continuously fed with raw sewage at a constant rate. In this way plant-scale operation is more closely simulated. In the conventional respirometer technique, on the other hand, the only recourse is to discontinuous feeding. Manifestly under a "glut and starve" regime, microorganisms behave differently and oxygen demand rates are apt to be affected.

3. Practically any level of dissolved oxygen and carbon dioxide may be

maintained in the aeration basin during the measurement period by feeding these gases into the booster device at appropriate rates.

4. The physical environment of the sludge in the model aeration basin more closely approximates conditions in a prototype basin than does the environment in small oscillating glass sample flasks used in respirometers. The energy and scale of the turbulence in the model basin may be adjusted to reproduce prototype conditions. Moreover, with both diffused air and oxygen the rate of oxygen transfer is not limited by surface aeration, as is the case in respirometers. Extremely high oxygen transfer rates may be attained, such as those encountered with the "super-activated" sludge investigated by Okun (5).

5. The theory of the method and the calculations are relatively simple. In addition to an evaluation of the flow rate, only D.O. measurements in the influent and effluent are needed. For example, in Run D of Smith's investigation, the following data were observed:

Sample	Dissolved Oxygen (p.p.m.) Before Oxygenation	After Oxygenation
Influent	$C_o = 8.15$	$C_o' = 43.30$
Effluent	$C = 1.70$	$C' = 4.10$

The flow rate was 0.142 l. per min. and the temperature was 25° C. Using Eq. 5, the oxygen transfer coefficient, $K\,A$, is evaluated as 1.94 l. per min. Substituting this value in Eq. 3, the uptake rate is found to be $X_o = 0.142\ (8.15 - 1.70 + 1.94\ (8.35 - 1.70) = 13.8$ mg. O_2/min.

6. The laboratory routine is simpler than that entailed in the use of manometric respirometer techniques. In particular, difficulties with gas leaks and shifting barometric pressures are circumvented. The apparatus is rugged and relatively easy to disassemble and clean. No laborious calibrations of flasks and manometers are needed.

Certain limitations of the method also appear from the investigation, as follows:

1. The aeration basin should have nearly "perfect" longitudinal mixing characteristics. That is to say, it should have a degree of mixing such that if a "slug" of a tracer (salt, dye, or radioactive isotope) is introduced in the influent it will appear quickly in the effluent with a concentration, u, formulated approximately by an exponential die-away equation,

$$u = u_o\, e^{-t/T} \ldots\ldots\ldots (11)$$

in which u_o is the initial tracer concentration that would result if the slug were dispersed uniformly throughout the tank, and T is the theoretical detention period of the tank. This type of longitudinal mixing obtains in model and prototype aeration basins having fairly small length/ width and length/ depth ratios.

In most activated sludge plants aeration bays are long and narrow and are equipped with transverse baffles to minimize short-circuiting. The longitudinal mixing characteristics of such basins differ from the "perfect" mixing on which the formulation embodied in Eqs. 1 to 6 is based. The formulation appropriate for basins with nonperfect mixing is complicated and entails measurements of D.O. at intermediate stations between the inlet and outlet.

This limitation of the method, it is believed, is not serious. Certainly the physical and chemical conditions in a model aeration basin such as described by the author approximate conditions in full-scale plants more closely than do those in small flasks in respirometers.

2. A second limitation of the method is that it does not permit an evaluation of the carbon dioxide balance in the tank, such as may be obtained with certain of the manometric techniques. This limitation is not inherent in the theory of the method, but stems from

the difficulty in making sufficiently precise analytic determinations of CO_2 in sewage-sludge mixtures.

It should be observed, however, that in manometric techniques a CO_2 balance may be made only when CO_2 traps of high efficiency are installed in the respirometer. With these, only small traces of CO_2 may be carried in dissolved form in the liquid sample. With some types of bacterial flora and nutrient substrate, the CO_2 level may affect the oxygen uptake rate. Optimum rates of stabilization of organic matter may be obtained with CO_2 present in amounts greater than trace levels. It would appear, therefore, that one of the principal advantages pertaining to the method described in the paper is that it may be carried out with any desired concentration of dissolved carbon dioxide.

PROGRESS REPORT ON WATER POLLUTION CONTROL IN CALIFORNIA

More than 156 California communities constructed sewage facilities costing in excess of $163,000,000 during the three-year period ending December 31, 1952.

This is one of the significant facts brought out in a recent report titled "Water Pollution Control—Progress Report for 1950 through 1952" and prepared by the State and Regional Water Pollution Control Boards at the request of the legislature. The state and nine regional boards were created in 1949 when extensive changes were made in state laws for the control of water pollution.

Of the 14 critical cases existing at the outset of the program, the report shows that 7 have been solved, 2 now are being solved, and 5 have been solved partially. During the reporting period, 72 successful bond elections for sewage works costing over $55,000,000 were held in California. In addition, waste treatment and disposal facilities were constructed at 27 local, state, and federal institutions.

The report points out that cooperation by industry, as well as public agencies, has been commendable. Waste treatment works were provided by at least 86 industries since 1949, and many industries are credited with initiating or broadening programs of self-policing and self-improvement in combating pollution.

Not only is the record of substantial progress presented in the report, but a chapter on "Unfinished Business" outlines the pollution abatement problems remaining in the state.

Because fact-finding comes first in solving water pollution problems, the boards report that more than 120 major investigations have been undertaken during the three-year period. Some of these studies pertained to immediate local problems; others pertained to long-range control programs. A stream sampling program is underway and involves the monthly collection of samples at 148 stations on 88 surface streams and lakes. Research projects have been or are being conducted on: water-quality criteria, leaching of salts from surface dumps, travel of pollution with ground-water movement, waste-water reclamation and utilization, and algae propagation in oxidation ponds.

The report has been printed as WPCB Publication No. 5. Copies are available upon request from any of the Regional Boards or from the office of the State Water Pollution Control Board, Sacramento, Calif.

SEWAGE PURIFICATION BY ROCK FILTERS—REMOVAL OF OXYGEN DEMAND OF SOLUBLE ORGANIC MATERIAL

By J. H. Sorrels and P. J. A. Zeller

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The trickling filter is one of the oldest and most popular devices for secondary treatment of sewage and wastes. Because of the many treatment units of this type in operation throughout the United States it is not surprising that much study has been devoted to the trickling filter. In fact, the "20-Year Index" (7) of the *Sewage Works Journal* lists about 200 articles on trickling filters, covering many phases of construction and operation. In spite of this impressive volume of literature, certain features of operation have received little attention.

One of the features neglected concerns the effect of the B.O.D. of soluble organic matter (hereafter called "soluble B.O.D." for convenience) and its removal or satisfaction by the trickling filter. There are many types of organic wastes containing a high proportion of soluble organic material. For example, in a recent comparison of series and parallel operation, Heukelekian, McMenamin, and Rand (1) stated that the sewage treated contained waste from the manufacture of candied fruit and was, therefore, high in B.O.D., sugar, and dissolved solids. It must have had a high proportion of soluble B.O.D. Velz (2), in an excellent discussion of filter performance, states the commonly accepted fact that B.O.D. in dissolved form is the most difficult to remove. On the other hand, McNamee (3) found that in the case of activated sludge, soluble and colloidal matter in sewage is oxidized more rapidly than had been generally realized. Although the organisms in the trickling filter and activated sludge are similar (4), physical conditions in the two systems are decidedly different. Consequently, there is no assurance that rates of oxidation observed in one system will also be obtained in the other. In all the literature, the authors have not found any direct study of soluble B.O.D. removal by the trickling filter.

This was a strong suggestion that such a study should be made to determine the ratio of soluble B.O.D. to insoluble B.O.D. in domestic sewage and to determine the quantities of each removed by a trickling filter. To this end, studies were initiated at the sewage treatment plant of the Agricultural and Mechanical College of Texas.

Method of Procedure

The A. & M. College of Texas is practically a municipality. At the time of these studies, the college sewage treatment plant served approximately 6,000 students plus that part of the operating personnel which is on the campus during the day. The sewage is domestic, with moderate amounts of wastes coming from a laundry, a creamery, an abattoir, and eating places. The plant consists essentially of primary sedimentation, trickling filter, secondary sedimentation, separate sludge digestion, and air drying of ripe sludge.

The experimental trickling filters used in this study have been described

in a previous publication (5). They were dosed with settled sewage from a common constant-head tank. No recirculation was practiced during these studies. Once or twice a week composite samples were taken hourly from 8 A.M. to 5 P.M., inclusive. At a B.O.D. of 200 p.p.m. in the applied sewage, the rate of flow was so adjusted that the loadings on the four filters were 450, 650, 1,000, and 1,500 lb. of B.O.D. per acre-ft. per day. The corresponding hydraulic rates were 1.7, 2.4, 3.7, and 5.5 m.g.a.d. Due to the usual variations in sewage strength, the actual loading varied somewhat. In every case, however, the loading was computed from the actual sewage strength and actual rates of flow recorded for that particular test or run.

The composite filter effluents were settled in Imhoff cones for 45 min. and a large subsample for all analyses was pipetted out without disturbing the sludge. The 5-day 20° C. B.O.D. was then determined on this subsample in the usual way. In addition, an aliquot of the subsample was centrifuged and the clear liquid passed through a 2-ml. asbestos mat in a Gooch crucible with suitable precautions to prevent dilution of the filtrate. The B.O.D. of the filtrate was taken as the soluble B.O.D. It is admitted that some colloids may pass through the asbestos mat. Preliminary tests were made comparing the B.O.D. of the Gooch and Berkefeld filtrates. Because the difference between the two was negligible, the simpler Gooch filter method was adopted.

The data on which this study is based covered a 9-month period from September, 1950, to May, 1951, inclusive, and represent a series of 34 separate tests.

TABLE I.—B.O.D. Loading Applied to Filters

Filter	B.O.D., 5-Day, 20°C. (lb./acre-ft./day)			Sol. B.O.D. (%)	Hydraulic Rate (m.g.a.d.)
	Sol.	Insol.	Total		
1	214	217	431	49.65	1.67
2	313	317	630	49.68	2.44
3	472	481	953	49.53	3.69
4	704	716	1420	49.58	5.50

Experimental Results

Table I shows the distribution of the applied B.O.D. attributed to soluble and insoluble material. It should be

TABLE II.—Reduction of Total B.O.D.

Filter	Total B.O.D., 5-Day, 20°C. (lb./acre-ft./day)			Total B.O.D. Reduction (%)
	Appl.	Effl.	Red.	
1	431	110	321	74.5
2	630	158	472	74.9
3	953	308	645	67.7
4	1420	780	640	45.1

TABLE III.—Reduction of Soluble B.O.D.

Filter	Sol. B.O.D., 5-Day, 20°C. (lb./acre-ft./day)			Soluble B.O.D. Reduction (%)
	Appl.	Effl.	Red.	
1	214	53	161	75.2
2	313	73	240	76.7
3	472	149	323	68.5
4	704	409	295	41.9

TABLE IV.—Reduction of Insoluble B.O.D.

Filter	Insol. B.O.D., 5-Day, 20°C. (lb./acre-ft./day)			Insoluble B.O.D. Reduction (%)
	Appl.	Effl.	Red.	
1	217	57	160	73.5
2	317	85	232	73.2
3	481	159	322	67.0
4	716	371	345	48.3

TABLE V.—Reduction of Volatile Suspended Solids

Filter	Vol. Susp. Sol. (lb./acre-ft./day)			Vol. Susp. Solids Reduction (%)
	Appl.	Effl.	Red.	
1	257	75	182	71.0
2	375	113	262	70.0
3	567	223	344	60.6
4	845	426	419	49.6

noted that approximately one-half the applied B.O.D. was soluble.

Table II is a summary of operating data based on the total B.O.D., Table III shows the reduction of soluble B.O.D., and Table IV shows the reduction of insoluble B.O.D. for each of the four filters.

Table V presents data on applied volatile suspended solids and their reduction through each of the four filters.

Figures 1 to 4, inclusive, illustrate

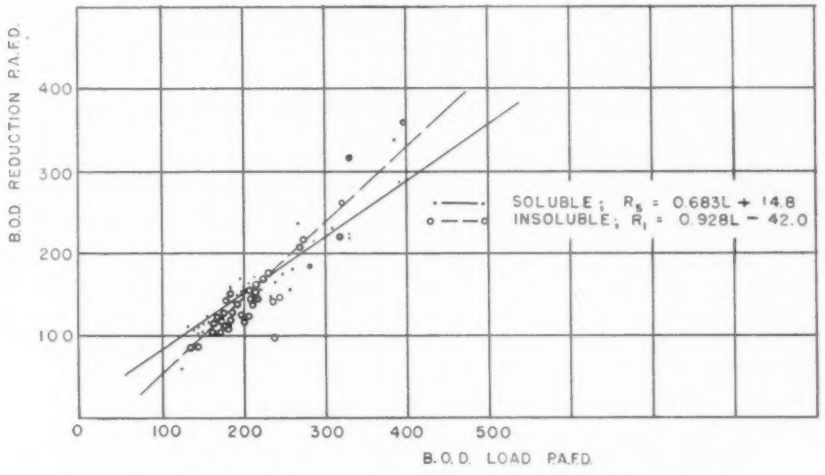

FIGURE 1.—B.O.D. performance of filter No. 1 at 1.67 m.g.a.d.

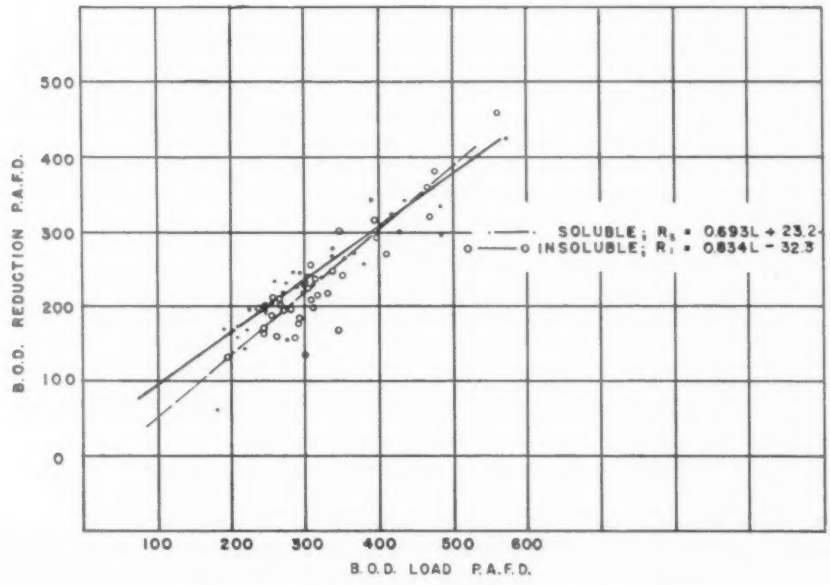

FIGURE 2.—B.O.D. performance of filter No. 2 at 2.4 m.g.a.d.

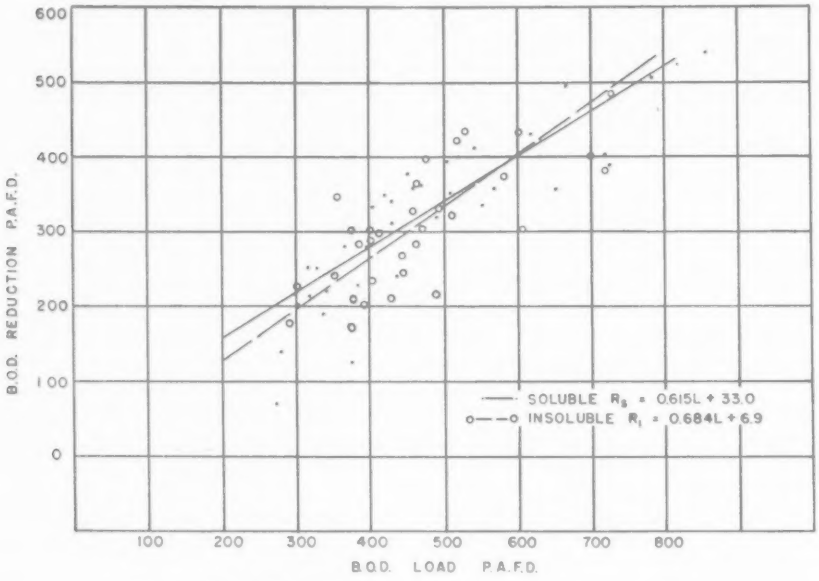

FIGURE 3.—B.O.D. performance of filter No. 3 at 3.7 m.g.a.d.

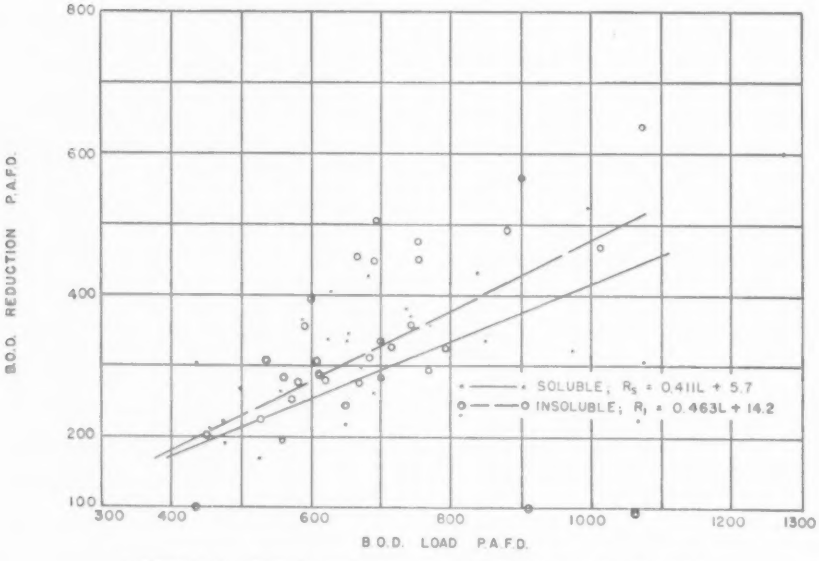

FIGURE 4.—B.O.D. performance of filter No. 4 at 5.5 m.g.a.d.

the performance of each filter in removing soluble and insoluble B.O.D. From any point on the curves, applied load and reduction can be read in the same units. The difference between the two values thus obtained is the effluent quality in pounds per acre-foot per day. The equation for each curve,

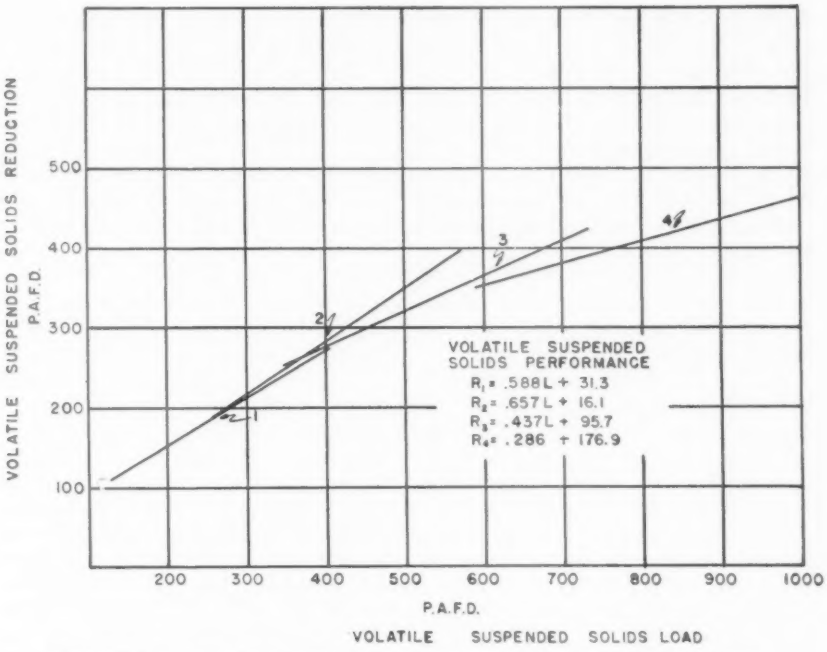

FIGURE 5.—Volatile suspended solids performance of experimental filters.

determined by the method of least squares, is also shown.

Figure 5 shows the loading and removal of volatile suspended solids, in pounds per acre-foot per day, for each of the four filters. Quality of the effluent at any loading may be computed as previously outlined. The equation for each curve is given.

Discussion

From Table I it is evident that the B.O.D. of the applied sewage was quite evenly divided between soluble and insoluble organic material. Because of lack of data from other plants, it is not known at present whether this distribution is usual or not.

From Table II it is to be seen that passage through the filter reduced the B.O.D. of the applied sewage, as was to be expected. The removal of B.O.D., however, was not constant, but changed with the load applied. Up to a loading of 630 lb. per acre-foot per day the removal was very nearly proportional to the load applied. When the loading was increased to 950 lb. per acre-foot per day, the removal increased, but at a slightly lower rate. The effluent remained of excellent quality. A further increase in loading to 1,400 lb. per acre-foot per day resulted in no further increase in removal, and the quality of the effluent deteriorated.

A comparison of Tables III and IV shows that the removal of soluble B.O.D. by filters 1, 2, and 3 was essentially the same as the removal of insoluble B.O.D. Filter 4, on the other hand, showed a slightly greater removal of insoluble than soluble B.O.D. As the loading increased from 200 to 475 lb. per acre-foot per day for both soluble and insoluble B.O.D. considered separately, the removal increased, but not quite in proportion to the increase in loading. In other words the percentage removals decreased very little as the loading increased. However, when the

insoluble B.O.D. loading was increased from 475 to 700 lb. per acre-foot per day, the removal increased very little. That is, the quality of the effluent deteriorated. With regard to soluble B.O.D., the removal actually decreased as the loading increased from 475 to 700 lb. per acre-foot per day; and the quality of the effluent deteriorated markedly. This decrease in reduction indicated that some unfavorable influence occurs between 475 and 700 lb. per acre-foot per day. This adverse influence will be considered later.

Figures 1 to 4 illustrate another important fact—namely, that for any of the four filters the removal of soluble B.O.D. is very close to the removal of insoluble B.O.D. This is contrary to the commonly accepted opinion. The slopes of the curves for insoluble B.O.D. removal are slightly greater than the slopes for soluble B.O.D. removal, which shows that the rate of removal of soluble B.O.D. is less than the rate of removal of insoluble B.O.D. but the difference is small. It is interesting to speculate what the differences in removals would have been if the relative proportions of soluble and insoluble B.O.D. in the settled sewage had been more uneven. Data are insufficient to draw any definite conclusions. The data from the 34 tests were divided into groups according to the percentage of soluble B.O.D. Analyses of these groups failed to indicate a significant trend.

It is shown in Table V that as the loading of volatile suspended solids is increased, the amount of volatile suspended solids in the effluent increases at an increasing rate. The rate of increase is moderate through filter 3, but jumps from filter 3 to filter 4. This is another indication of the break in continuity at high loadings. The trend is probably seen more easily in Figure 5. As the loading in volatile suspended solids increases, the slope of the curves tends to decrease at an increasing rate. Further, there was a more pronounced scatter of points in the case of filter 4, which received the highest loading.

The curves in Figures 1 to 5, representing the performance of the individual filters, present an interesting question. Are these curves for any specific constituent significantly different from each other, or can the system be considered as homogeneous and therefore be dealt with as a composite unit?

If the filters represent a homogeneous set of conditions they can be considered as a composite unit. This would be of considerable importance in the application of performance data to the design of such filters for plant-scale treatment. The plotted points of the results of filter 4 were more widely scattered than were those of the other filters, indicating more divergence and variation. The correlation coefficients for this filter were also considerably lower than those for the other filters.

Standard statistical tests (6) were applied to the data to determine if the regression coefficients were homogeneous. From these tests it was found that the coefficients were not homogeneous for all four filters, but were homogeneous for the first three filters. The first three filters may, therefore, be considered as homogeneous and dealt with as a unit.

Figure 6 indicates the performance of the first three filters considered as a unit. The relationship between applied load and removal for each of the constituents appears to be linear for the range of loading considered in this study. In the discussion here with reference to consideration of the filters as a unit, the definition is limited to those performance data which would represent a linear relationship between load and reduction. It is recognized that the four filters may be considered as a unit, but the relation is apparently curvilinear, as indicated in Figure 5.

The upper limit of total B.O.D. at which the efficiency drops rapidly may possibly be a point at which the filter

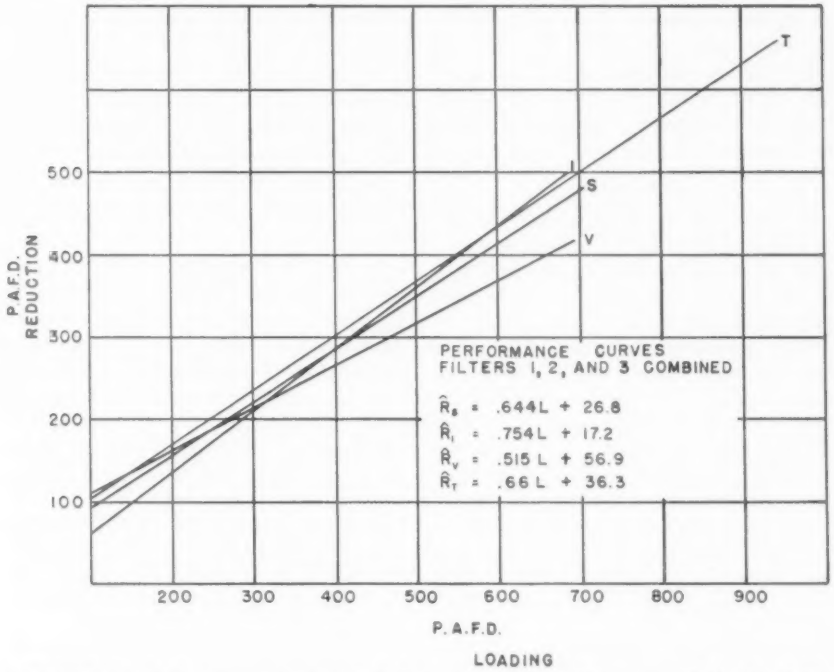

FIGURE 6.—Performance curves of all four experimental filters on soluble, insoluble, and total B.O.D., and volatile suspended solids.

becomes saturated and loses its ability to oxidize B.O.D. as readily as at lower loadings. There seems to be a maximum removal of B.O.D., regardless of applied loading.

Correlation coefficients were calculated to determine the relationship between (a) total suspended solids and insoluble B.O.D., (b) volatile suspended solids and insoluble B.O.D., and (c) hydraulic rate of B.O.D. reduction. In each case low coefficients were obtained for each filter. This was not too unexpected in the first two cases, as there must be a wide range of variability in the degree of oxidation of the suspended solids in settled sewage. In the case of hydraulic rate and B.O.D. reduction, the low coefficients emphasize the fact that the performance of a trickling filter depends more upon the organic load applied than upon the hydraulic rate of application of such load.

Summary

Four experimental trickling filters, each 4 ft. square with 6 ft. of gravel medium, were operated for 9 months on settled sewage with an average B.O.D. of 186 p.p.m. The average loadings were 431, 630, 953, and 1,420 lb. per acre-foot per day. Corresponding hydraulic rates were 1.7, 2.4, 3.7, and 5.5 m.g.a.d. The B.O.D. was separated into two fractions—that which passed through a Gooch filter, and that which did not. The former fraction was called soluble B.O.D.

For the particular sewage studied, soluble B.O.D. averaged one-half the total B.O.D. The results showed that for loadings of applied total B.O.D. from 100 to 1,000 lb. per acre-foot per day, removals of soluble B.O.D. and insoluble B.O.D. were virtually equal. As the loading increased, however, the rate of removal decreased, with a fairly

sharp break between 950 and 1,400 lb. per acre-foot per day. Removal of suspended solids followed the same general trend. There was little correlation between removal of suspended solids and removal of insoluble B.O.D.

Conclusions

1. Soluble B.O.D. in domestic sewage is removed at approximately the same rate as insoluble B.O.D. in trickling filters at loadings from 100 to 700 lb. per acre-foot per day.

2. At approximately 950 lb. per acre-foot per day total B.O.D., the rate of satisfaction begins to decrease rapidly.

3. Soluble B.O.D. removal is more dependent upon the organic loading applied to the filter than upon the hydraulic rate of application.

4. Little correlation exists between volatile suspended solids and insoluble B.O.D.

5. Within the range of 100 to 1,000 lb. per acre-foot per day total B.O.D. applied, the relation between the reduction and loading is linear. Outside these limits the relation is not linear.

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PUBLIC SEWAGE TREATMENT PLANT CONSTRUCTION—1952

A summary of construction of public sewage treatment works for the calendar year 1952 is contained in a 19-page report recently released by the Division of Water Pollution Control, U. S. Public Health Service, under the title "Public Sewage Treatment Plant Construction—1952," and designated PHS Publ. No. 291.

According to the report, contracts amounting to $137,000,000 for 515 sewage treatment plants, including interceptor sewers, were awarded by U. S. municipalities during the year. The cost of 314 new plants was $78,419,556, the remaining $58,789,133 providing for additions, enlargements, or replacements to 201 existing plants. The contract total for 1952 compares with similar totals of $158,000,000 in 1948, $180,000,000 in 1949, $203,000,000 in 1950, $177,000,000 in 1951, and an estimated annual requirement of $450,000,000 to $500,000,000, for known pollution abatement and expected needs arising during the 10 years beginning in 1950.

An appendix of 7 pages lists, by community, the individual sewage treatment plant construction contracts awarded during 1952, giving the type of construction and cost in each case.

ARE SEWAGE WORKS COSTS JUSTIFIED?*

By L. L. Sphar

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This paper is presented from the viewpoint of one who is not a designer, operator, public official, or equipment specialist. Viewing the field as a contractor, after having been in design, has led to the strengthening of a conviction that had been growing for some time: the conviction that much more attention ought to be given to the matter of obtaining greatest over-all economy in the development of public works projects such as sewers and sewage treatment plants. And as a contractor, it is possible to present, perhaps more frankly than might otherwise be expedient, the following remarks concerning economic justification.

Inception Phase

First, there is the inception phase of public works—the phase that precedes design. Public officials need to be very discerning to avoid being misled into embarking on ill-advised projects. A great deal is owed to the promoters, but it must be remembered that sometimes promoters have motives other than unselfish interest in the public welfare. Moreover, the art of promotion generally involves a scrambling of fact with fancy, and a mixing of understatements and overstatements best calculated to achieve the desired end. It is of first importance to make certain that the project itself is justified; and it is the well-defined responsibility of professional engineers to honestly advise public officials in this regard.

Before a sewage project is turned over to the engineers for design, there are usually certain restrictions imposed —by officials who are experts by reason of having been elected to office; by the general public, which mirrors the efforts of propagandizing organizations; by these organizations themselves; and, of course, by the various regulatory agencies; and by combinations of all these. These restrictions may frequently be incompatible with principles of economic justification, and when so, should be resisted by the engineer to the limit of his ability.

Consider the restrictions sometimes imposed due to the influence of sportsmen's and conservationist groups. The motives of these organizations may be above question, but their zeal may take on very unreasonable aspects due to lack of appreciation of the simple fact that engineering problems ought to be resolved by engineers. For example, secondary treatment has become popularly known as complete treatment. On the premise that what isn't complete must obviously be incomplete, in the sense that something is lacking which ought to be there, these people have exerted and are exerting very considerable influence to require treatment that cannot be justified by technical analysis. It seems to be impossible to convince a conservationist that there is nothing incomplete about any plant which does everything that needs to be done to the particular sewage at a particular place. In one instance the determined resistance to the efforts of a politically powerful sportsmens'

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group, by the engineers, commissioners, and attorney for a large sewer district, over an extended period of time and through several legal skirmishes, did suffice to prevent the completely unwarranted expenditure of a couple hundred thousand dollars. In how many other instances is this sort of resistance lacking or ineffective?

The foregoing should not be misunderstood. The sportsmen and conservation people deserve great credit for their part in arousing the public to the need for pollution control. Those who can see a larger picture, however, should not sit idly by and allow ideas to be built up in the public mind and made public policy which are erroneous and likely to result in the unwise expenditure of large sums of money. Wastefulness of public funds is every bit as wrong as the squandering of natural resources so often discussed.

The Pacific Northwest Sewage and Industrial Wastes Association itself encourages an unwise restriction, in that it is on record as advocating a minimum of primary sedimentation and separate sludge digestion for all treatment plants. This is wrong. Each community should be permitted to meet the water quality standards established for its particular receiving body of water by whatever means its engineers may devise. It is possible that in 99 cases out of 100 the minimum previously stated would apply; but it nevertheless would be wrong to require the hundredth community to comply if some other process less costly would suffice for its particular situation.

Design Phase

Now that a project has been wisely conceived, and the unreasonable restrictions have been weeded out, the next phase is design.

First of all, the right engineer should be selected. There is generally little difference in the amount of the fee, and the fee itself is a minor portion of the total cost of a project. But there may be a very great difference in the quality of service rendered and in the consequent over-all cost. Careful inquiry ought to be made into the past records of prospective engineers, to make certain that ample experience in work of a similar nature has preceded the particular project under consideration. This is not to belittle young men or new firms; but young men ought to serve their apprenticeship before undertaking work on their own, and new firms ought to be led by men of sufficient experience.

One thing to watch out for is the occasional engineer who, although perhaps qualified and respected in his own field, has not had much experience in the specialized field of sewage works. This man finds an opportunity to take on a sewage project and, perhaps not realizing his own limitations, is unable to resist the chance to earn what he may consider to be a very fat fee. The result may be anything from barely passable to downright deplorable, depending on how much and what kind of advice he has accepted from which equipment salesman. It is almost axiomatic that the more qualified the engineer, the more likely that an economically justified and properly operable installation will result.

The engineer is obligated to produce for his client not only a workable design, but also an economical one. This obligation is usually felt, except when the client happens to be a state or federal agency. In that case the current philosophy seems to be that as long as they're throwing it around like dirt anyway, a little more won't hurt—and the fee is in proportion to the cost! How does one explain a system of morality which makes it right and proper for otherwise honest men to "take" the government for everything possible? The obligation to produce the most economical design should be more than just felt—it should stand out as a principal rule of professional conduct, irrespective of who the client may be.

Economy of Design

There are a few points relative to economical design that should be discussed.

Engineers develop "pet" designs and details, which they tend to apply to all situations. However, such consistency is inconsistent with principles of economy. A good example may be found in sewer pipe-line construction. It is unreasonable to call for exactly the same kind of construction for every project, but some engineers do this. The current interest in control of infiltration has given rise to a number of new types of pipe and joint construction, and some of these do produce excellent, tight lines. It is possible, however, for such construction to cost more than it is worth, although it is more likely that the "throw-it-in-the-ditch-and-cover-it-quick" method will turn out to be more expensive.

The point is that each project should be analyzed and a method of pipe construction chosen which will be best for that particular situation. Obviously, where sewage must be pumped or put through extensive treatment, a high-type sewer construction is indicated to keep infiltration to a minimum. On the other hand, in a situation where there is to be no pumping, only moderate treatment, and the lines are laid above water table in impervious soil in an arid climate, such expensive sewer construction would be wasteful.

The annual cost per unit of infiltration can be approximated for a particular project, by taking into account pumping cost, plant and trunk size, chemical cost, etc. The relative costs of different types of pipe-line construction can then be applied to determine which will produce the lowest over-all cost. Accurate pipe-line cost comparisons can be made by having the contractors bid on alternate designs based on several infiltration limits. The contractor should be required to guarantee the infiltration limits as bid, and should be permitted his own choice of construction method to meet the requirement. The practice should be established of permitting the contractor to exceed the infiltration limit by some fixed percentage in various runs of pipe, provided this overage is balanced out in other runs of sewer so that the total infiltration is within the limit fixed and no section of the pipe is overloaded. This of course would necessitate measurement of infiltration from manhole to manhole, which ought to be done in any event. It also brings up problems beyond the scope of this paper. A comprehensive paper is needed on the subject of infiltration limits, methods of control, methods of measurement, and methods of specification writing to accomplish the desired results with optimum economy.

The most economical sewer design is the one that produces the lowest sum of construction and operating cost for the whole system. Having bid on several infiltration limits, and having been awarded the contract on the basis of a particular infiltration limit which produced the lowest over-all cost, the contractor would be conditioned to really accept infiltration as of the essence of the contract. As a further refinement of this idea, a reward or penalty clause could be written into the contract by which the contractor would be rewarded for achieving measured infiltration less than bid, or penalized for failing to meet his guaranteed infiltration. Of course such a clause could permit overage only within the capacity of the system. The reward or penalty would be made to correspond to the computed operating cost per unit of flow, so that the owner could not lose either way; but the contractor would be given a real incentive to produce good work. Furthermore, there would be an important reduction of risk, since the contractor would have the continuing option, when unexpected difficult conditions arise, of attempting to meet a rigid specification or deliberately accepting the penalty for excess infiltration.

This has been an illustration of the principle of considering the sum of first cost and operating cost in determining most economical design. It ought to be unstintingly applied to all phases of design of all projects.

For example, a few minutes scratching with a pencil will serve to determine whether an automatic chlorinator is more or less economical than a manual machine; or whether the increased cost of a plant capable of handling bulk chlorine will be offset by the resulting savings in cost of the chemical.

The current fad of superinstrumentation has been criticized in the field of military mechanisms. It might well be examined also in the field of sewage treatment plant design. Gadgets are of value only to the extent that they are necessary to the plant process and reduce operating cost. It is easily possible to load a plant with "gimmicks" whose useful virtues are far outshadowed by the cost in man-hours of the tinkering they require. After the essential processes have been provided for, the criterion should be: Does the device decrease operating cost?

A full-time employee at $3,600 per year is equivalent to some $40,000 worth of plant first cost. That is, labor-saving devices costing up to $40,000 can be justified if they actually reduce the operating force by one man. The retirement of the $40,000 plus the operating and maintenance costs of the devices will about equal the salary of one man. If the community can use men part time at other work, as often happens, the engineer can use smaller units down to, say, $5,000 in plant cost, equal to 1 man-hour per day. Plug valves, for example, instead of gate valves, should by this criterion be almost always justified where there must be daily operation. But the man-hours saved must be available for other work. If the plug valves merely enable the operator to take two hours for lunch instead of one, they are not justified.

Digester insulation can be balanced against the cost of auxiliary heating. Such analysis would probably result in better insulated digesters and also, probably, an increased use of sludge thickening devices to eliminate unnecessary heating of supernatant liquor.

There is a tendency to over-emphasize laboratory control. One cannot object to the provision of equipment for essential control of process; but should the operator be burdened with the necessity of taking a lot of data useful only to designers of other plants or to people who are occupied with the collection and compilation of statistics? Or should his community be burdened with the cost of the equipment involved in the collection of such non-essential data? "Canned" lists of laboratory equipment, ambitiously prepared by officials not concerned with costs, ought to be carefully edited to fit the particular plant requirements before inclusion in the specifications.

Regardless of the possible usefulness of laboratory data, much of it is of doubtful value, especially that from the smaller plants, due to the fact that the small plant operator can seldom be an expert laboratory technician and still manage his many other duties. Perhaps wider use could be made of mobile laboratory equipment operated by skilled technicians working under the proper state agency, or arrangements might be made with local school authorities for a school chemistry department to take over the collection of laboratory data as a training project, utilizing school equipment.

Improvised mechanical devices generally should not be designed into a plant; equipment development is best left to people in that business. Surely, progress involves pioneering, and the inventive genius is the salt of the profession. Nevertheless, new devices invariably have bugs to be worked out, and the unsuspecting community should not be required to bear the expense and inconvenience of the ex-

perimenting. It's a funny thing—if an idea works out perfectly, the originator doesn't get much credit; he's been paid to design something that works. But when the bugs show up, down comes the wrath of the gods!

Standard details and stock designs are the other extreme. They have their place; but unless they provide the best design for the specific problem, their place is right back in the file.

A standard part of design procedure should be to have a good field man in the organization go over the completed plans to weed out impractical details. Draftsmen sometimes dream up some queer details, and since the bidding contractor can't be sure that he will be able to effect a revision, he naturally bids a little higher to cover the possibility of having to follow the detail exactly. Concrete construction joint arrangements and details, and piping details, seem to offer the best opportunities for draftsmen to go wrong.

Bidding

Finally, the project should be set up so that it can be bid and constructed in the most economical way.

The principal point to be made here is that the less risk incorporated in the plans and specifications, the more competitive will be the bidding, and the more likely it will be that a reputable contractor will be low bidder. It must be obvious that contractors load their bids to cover risk items. Therefore, if no subsurface data are given, or no unit prices are set up to cover quantities not determinable in advance, or no assurance is given that unanticipated work will be paid for as extra, the reputable contractor will bid high to cover himself against the hazard, or will not bid at all. If the specifications are full of self-exonerating clauses, indiscriminately holding the contractor responsible for everything, including errors of omission, the result will surely be higher bids. If the specifications are filled with "canned" pages so that the contractor must guess at what will be enforced and what held not to apply, up go prices.

In this connection, the engineer, himself constitutes the biggest element of risk. How will he enforce his specifications? It is surprising to learn how widely contractors' evaluations of engineers get around; and how directly this affects bidding. Of course, deviation on either side of fairness is costly to the owner. The tough engineer will draw less bidders and higher prices, whereas the overly generous engineer may more than offset the advantage of favorable bids by making excessive payments.

This bears repeating: to secure good bids and a responsible contractor, eliminate the risk items. It is possible to get a low bid on any bid call from an inexperienced or irresponsible contractor, but the result will be no bargain. No amount of policing can get a good job out of a contractor who is losing his shirt, who doesn't know how, or who just doesn't intend to give a good job.

How to Secure Better Bids

Engineers could do a great deal more than is customary to facilitate bidding and thus achieve better bids for their clients. At best the preparation of a bid on a complex job is a terrific task, and there is never enough time. Here are some things engineers might do to help relieve the time situation:

1. Use unit prices as much as possible. This is not only a big time saver, it eliminates an important element of risk. Bids on unit price contracts practically always are closer together than lump sum bids.

2. Furnish bidders with sources of supply of specialty items. Equipment quotations never come through until the last minute anyway, and it is not uncommon to find, when it is almost too late to do anything about it, that nobody has quoted some item or other. Advise suppliers of special items that you have specified their product, so

that they will get quotations out. This applies to the minor mechanical items, special valves, controls, and the like, and to hard-to-find materials like filter rock.

3. Furnish local subcontractors with data so that they will be prepared to quote. Painters, roofers, sheetmetal contractors, millwork suppliers, electrical and mechanical contractors, masons, and similar specialists in the immediate vicinity of a project can generally quote better prices than subcontractors from farther away. But it is amazing to find how frequently local people are not made aware of a project in their own vicinity until too late to quote.

4. Use more care in separating items so as not to confuse the quotations of the various subcontractors. It can become quite tedious to break down the quotations of half a dozen subcontractors to put together a price on a thoughtlessly selected bid item.

Careful attention to these and similar details by the engineers should materially simplify the process of bidding. With more time and opportunity for detailed job analyses, contractors ought to be able to figure their costs more exactly, and this would make for better bids.

Contractor's Financing

There is one other matter. Contractors must have money to invest in each project for payroll, materials, plant, and overhead. On a closely figured job the contractor may not have his money out until after the final retained percentage has been paid (and, of course, sometimes not even then). This money is usually borrowed at bank rates. Anything that can be done to lessen this financial burden will enable more contractors to bid, and will permit them to bid a little lower. Purchase of equipment and materials directly by the owner has this effect, although there are some disadvantages. Also, if the owner has funds on hand at the beginning of the project, as is frequently the case, it is profitable to finance the contractor by whatever means are available, if only to gain the interest differential.

Bids might well be set up so that large payments become available very early in the construction program. The A.S.C.E. handbook on "Construction Cost Control" (1) has some interesting comments on this. Contractors, of course, often unbalance their bids to obtain large payment estimates at the beginning of a job, but the practice can result in very inequitable situations when bid quantities are later changed. It would seem to be much more desirable to set up an item especially to give the contractor the benefit of early large payments.

Summary

In presenting a paper of so broad a scope, it has been necessary to touch but lightly on subjects sufficient for a dozen papers. Many things had to be left unsaid; many arguments perhaps left unclinched. Statements involving matters of opinion have been made without proper qualification, but the purpose of the paper has not been to establish the validity of an assortment of separate ideas, but rather to point up a general conclusion, as follows:

Are sewer and treatment plant costs justified? All too frequently they have not been. How to correct the situation is not a matter of applying a list of specific cost-cutting suggestions. What is necessary is the adoption—or reaffirmation—of an attitude. Sewer and treatment plant costs will be justified only when engineers begin to think and act in terms of over-all economy, husbanding public funds as though they were their own, as they really are, all the way from inception of the project, through design and construction, and into operation.

Reference

1. "Construction Cost Control." Amer. Soc. of Civil Engr., New York, N. Y.

AN EVALUATION OF THE OXYGEN CONSUMED TEST *

By Hazel V. Roberts and Wallace W. Sanderson

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Although the oxygen consumed test has never assumed the importance of the biochemical oxygen demand determination, it has a definite value in the examination of sewage and industrial wastes. It is often an advantage to know something about the oxygen demand of a sample within a few hours of collection, rather than waiting for a 5-day period. Also, certain industrial wastes containing chromium, copper, or other substances that inhibit biological growth make it impossible to determine the biochemical oxygen demand by the usual procedures. In this case, an estimate of the amount of oxygen utilized by the sample may sometimes be made from the oxygen consumed from a standard oxidizing agent.

The oxygen consumed test has sometimes been confused with the chemical oxygen demand, which is actually a different test. The chemical oxygen demand, or C.O.D., has always been associated with the B.O.D. determination. It represents the immediate oxygen demand of the sample taken for the B.O.D. test, or the oxygen depletion determined 15 min. after the sample is diluted, rather than at the end of 5-day incubation. The value obtained in this portion, examined before measurable biologic action begins, is known as the chemical oxygen demand and, if present, should be subtracted from the value obtained at five days if the actual B.O.D. is to be determined.

The oxygen consumed value is that amount of oxygen utilized by a sample when treated with a standard oxidizing agent under a given set of conditions. It is an empirical value based on the kind of oxidant used and its strength. In some cases it also depends on the size of the sample and the length of contact time. The oxidant should always be stated, because there is great variation in the effectiveness of the various oxidizing agents employed and, therefore, in the results obtained. Since the determination recommended for the new edition of "Standard Methods for the Examination of Water and Sewage" will probably use dichromate, the designation should be "oxygen consumed from dichromate" or, if initials are preferred, it could be called "D.O.C."

The oxygen consumed from permanganate, which is now the standard method (1), has long been known to have serious disadvantages. First, it is not an effective oxidant for many of the organic compounds found in sewage, and especially in industrial wastes. The results are affected greatly by the strength of the permanganate and the size of the sample. Effects of the latter can be somewhat minimized by using a portion such that at least 25 per cent but not more than 50 per cent of the available permanganate is used in the oxidation. Time and temperature will also cause variations, and although the time of digestion has been standardized at ½ hr., the temperature may vary during that interval, causing lack of reproducibility of results.

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Comparison of Proposed O.C. Tests

Moore (2)(3) has made extensive studies on several types of oxygen consumed tests. He chose four tests to compare with the "Standard Methods" (1) permanganate method. Three of these use potassium dichromate as the oxidizing agent and one employs iodic acid.

The iodic acid method developed by Dzyadzio (4) and used by Johnson, Tsuchiya, and Halvorson (5) is a long and complicated procedure which has good oxidizing power and also good reproducibility. In this method, a portion of the sample of waste is placed in a Kjeldahl flask, measured amounts of standard potassium iodate and sulfuric acid are added, the flask is placed in a bath of wax and heated to 190° C. for 35 min. after the contents of the flask have stopped boiling. If the wastes contain volatile acids, they must be refluxed for 1 hr. instead of the digestion. At the end of the time, the flask is cooled, the excess iodine is driven off by steam distillation, potassium iodide is added to convert the remaining iodate to free iodine, and the iodine is titrated with sodium thiosulfate, using starch as an indicator.

This method required the most time and equipment of any studied, but produced very good agreement among replicate samples and a higher percentage of the theoretical value for oxidation of pure compounds than most of the other tests. Results obtained with different sized samples up to 40 ml. checked well, but there were poor checks on the blanks.

The Madison method (6), an adaptation of earlier technics, utilizes dichromate as an oxidizing agent in the presence of sulfuric and phosphoric acids. Oxidation is accomplished by boiling the sample and fuming the residue for exactly 4 min. The mixture is then cooled, diluted, and the excess dichromate titrated with ferrous ammonium sulfate, using sodium diphenylamine sulfonate as an indicator.

This method is subject to wide variations in results because of the difficulty of maintaining the 4-min. fuming period and the lack of definition in the end point of the titration.

The method of Ingols and Murray (7)(8), also using dichromate, calls for refluxing the sample with the oxidizing agent at 145° C. At the end of 1 hr., potassium iodide solution is added, and the free iodine is titrated with a standard sodium thiosulfate solution.

This method has an advantage in that it is much easier to carry out, does not have to be watched so closely during oxidation, and yields more reproducible results. However, the use of an iodine titration in the presence of dichromate yields a poor end point, which may interfere with the precision of the test. In this test a blank is needed, but it must not be refluxed before titrating because the dichromate breaks down and low results may be obtained. It is essentially bad practice, however, to use a blank which has not been treated in the same way as the sample.

U. S. Public Health Service Method

The dichromate method developed by the U. S. Public Health Service (9) seems the most satisfactory of the many methods proposed, both in oxidizing power and in time required for the test. In this procedure a measured quantity of standard potassium dichromate solution is added to an aliquot portion of the sample to be tested, and sulfuric acid is added to make the resulting solution 50 per cent acid. This is refluxed for 2 hr., cooled, diluted with water, and titrated with ferrous ammonium sulfate, using orthophenanthroline as an indicator. To determine the amount of oxygen used by the sample, the amount of the titration is subtracted from that obtained from a blank treated in the same manner. This method uses relatively simple equipment, and although the total elapsed time is slightly longer than for

TABLE I.—Oxygen Consumed Determinations on National Aniline Division's Plant B and C Effluents[1]

Item	Method				
	Iodate	Ingols	Madison	Permanganate	USPHS Dichromate
No. of determ.	99	96	99	98	100
No. of replicates	5	10	10	10	10
Mean	960	1,153	690	463	1,183
Range	223	591	1,184	169	113
Stand. dev.	39.42	73.6	211.1	33.29	15.87
Confidence limit, single determ.	110	166.3	477	75.1	35.8
Time for indicated number of replicates (hr.)	7¾	3¾	7	3	4¼

[1] Adapted from Ref. (3).

some of the tests, it requires no attention during the 2-hr. refluxing period. The end point is a sharp, easily distinguishable color change from green to red.

Table I shows the results of Moore's comparison of the five methods (3), using 10 replicates of 10 samples of an industrial waste. It can be readily seen that the Madison method had the greatest amount of variation, with the average obtained very close to that of the standard permanganate test. The U. S. Public Health Service test gave the highest results and the best reproducibility, with the Ingols test not far behind on high results, but the iodic acid method next on reproducibility.

Moore (9) has also done considerable research on the per cent of theoretical oxidation of various pure compounds obtained by the U. S. Public Health Service dichromate test. He found that, in general, branched-chain hydrocarbons, sugars, and phenolic compounds were readily oxidized, but straight-chain acids and alcohols and such compounds as benzene, pyridine, and toluene were not. Chlorides are oxidized quantitatively by this test and, therefore, their effect must be determined and subtracted from the total.

Effect of Silver Sulfate

It was found later, however, that the addition of 1 g. of silver sulfate to the sample before refluxing caused a marked increase in the oxidizability of the straight-chain acids and alcohols (Table II). Acetic acid, which was scarcely attacked before, now is oxidized to 95 per cent of the theoretical, whereas lactic acid found in milk plant wastes, and sodium stearate from soaps, are broken down to a great extent. Benzene, pyridine, and toluene remain unchanged. Table III shows comparative results on various types of samples run in the New York State Division of Laboratories and Research. Unfortu-

TABLE II.—Effect of Addition of Silver Sulfate on Dichromate Oxygen Consumed[1]

Compound	Per Cent of Theoretical Oxidized	
	Without Ag_2SO_4	With Ag_2SO_4
Acetic acid	2.4	95.1
o-cresol	83.2	95.8
Ethyl alcohol	29.7	80.1
Glutamic acid	63.9	100
Lactic acid	45.4	82.7
Sodium stearate	74.2	91.7
Benzene	7.8	8.1
Pyridine	1.3	0.8
Toluene	21.4	22.5

[1] Adapted from Ref. (2).

TABLE III.—Comparative Results (in P.P.M.) of Oxygen Consumed Tests on Various Types of Wastes

Type of Waste	With Ag_2SO_4	Without Ag_2SO_4
Apple processing	5,900	4,200
Milk	324	266
Milk	76	39
Milk	741	607
Milk	359	302
Milk	1,500	1,300
Milk	577	479
Airplane washing	376	336

nately, however, silver is incompatible with some samples and precipitates, causing lower values than would be obtained with its use. This is particularly true in the presence of high chlorides. Therefore, silver sulfate should be used only on those wastes actually needing it, and should not be used indiscriminately on all samples.

Discussion

The U. S. Public Health Service dichromate method has been in routine use in the New York State laboratory since 1950. When it was first introduced, samples of sewage, industrial wastes, and streams were examined, for comparison, by both the permanganate and the dichromate methods. As might be assumed, the dichromate oxygen consumed was higher in 47 of 52 samples examined, but there was no correlation between the results of the two tests because of the complexity of the organic matter in each sample, some of which may be partially or completely oxidized by both permanganate and dichromate and some which may be attacked by dichromate only. Of the 47 samples which gave higher results with dichromate, 38 were more than twice as high, and of these 7 were more than five times as high. The latter condition occurred mostly in stream samples taken below the discharge of industrial wastes.

Much has been said concerning the relationship between the oxygen consumed value and the B.O.D. with the idea of using the oxygen consumed, which can be obtained quickly, to estimate the B.O.D. In domestic sewage, and probably in unpolluted streams, there is a relatively definite ratio between the two values; but with industrial wastes or streams containing these wastes, no predictions can be made as to correlation because of the materials present, which may be oxidized by the dichromate, but not by biological activity, or the reverse. Riehl (10) reported that for straight domestic sewages, in general, the 5-day B.O.D. was reasonably close to 65 to 70 per cent of the dichromate oxygen consumed results. The present results on raw sewage with B.O.D. between 100 to 300 p.p.m. showed a wider spread of from 50 to 70 per cent. The relationship in the effluents followed a very definite pattern. For B.O.D. values above 50 p.p.m. the B.O.D. represented from 50 to 65 per cent of the oxygen consumed; between 20 and 50 p.p.m. the B.O.D. was equal to 25 to 30 per cent of the oxygen consumed; and below 20 p.p.m. results were variable, but all were less than 25 per cent of the oxygen consumed value.

Summary

The U. S. Public Health Service dichromate oxygen consumed test as used by the New York State laboratory has proved to be a very useful determination. In general, it is less affected by differences in the physical conditions of the test situation than the permanganate method and, therefore, yields more reproducible results among various samples. It has a high oxidizing power and, with the addition of silver sulfate, it will attack almost all of the compounds one would meet in sewage or industrial wastes, with the exception of benzene, toluene, and pyridine. The method has, however, one disadvantage in its use where samples have a low oxygen consumed value, such as those from unpolluted streams. Since the strength of the dichromate and ferrous ammonium sulfate used is N/4,

a titration of 0.1 ml. gives an oxygen consumed value of 4.0 p.p.m. if the maximum 50-ml. sample is employed. Therefore, low oxygen consumed values cannot be accurately determined and the test would be valueless for drinking water unless it could be sufficiently adapted.

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MAKE YOUR HOTEL RESERVATIONS EARLY FOR THE FSIWA MIAMI MEETING

Miami, Fla., will be the locale of the Federation's Twenty-Sixth Annual Meeting, to be held October 13–16. An interesting, informative, and entertaining program is being planned for the four-day meeting, which will utilize the excellent facilities of the city's Bayfront Auditorium.

Requests for room reservations should be addressed directly to the FSIWA Housing Committee in Miami, as indicated on the inside front cover of this issue. It should be noted that the meeting this year will begin on the morning of Tuesday, October 13, and close at noon on Friday, October 16.

WRITE NOW FOR YOUR RESERVATIONS!

THE BRITTINGHAM LABORATORY PUMP

By L. R. Setter, W. E. Brittingham, and R. F. Wessels

U.S.P.H.S. Environmental Health Center, Cincinnati, Ohio

A number of laboratory pumps have been designed in which a flexible tube is mechanically collapsed by a roller (or finger) in such a manner that the fluid (or gas) in the tube is pushed forward (1) (2) (3) (4) (5). Additional fluid (or gas) is drawn into the tube as the tube expands behind the roller. Usually the rollers squeeze the flexible tube against a stationary backing plate or track. As a consequence, the flexible tubing is usually subjected to excessive fatigue. It is also quite imperative in such a pump that the tubes of a multiple unit be of the same wall thickness.

The Brittingham pump largely overcomes the two objections mentioned by eliminating the stationary track. Instead, the flexible stretched tube is rolled over by three or four rollers on a rotating disc and is supported at the suction and discharge ends of the pump (Figure 1). The tube shown in Figure 1 has been pumping tap water continuously for the equivalent of two months without signs of fatigue. In this model the four rollers, each 1 in. in diameter and 3 in. long, are mounted at 9.5-in. centers on the 6.75-in. radius of the rotating disc. Collars made by wrappings of friction tape with or without standard pipe fittings are secured to the ends of a given tube length. The tubing is slipped through slots in the support post to holes of the diameter of the tube in such a manner that the tube collars rest against the support. The tube is then stretched from the support post over three of the rollers, as shown.

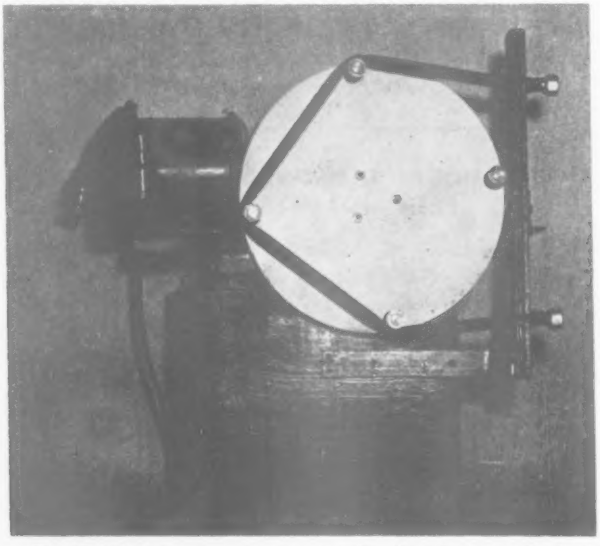

FIGURE 1.—The Brittingham squeegee pump, showing the motorized disc with four rollers that progressively squeeze a rubber tube at three points of contact.

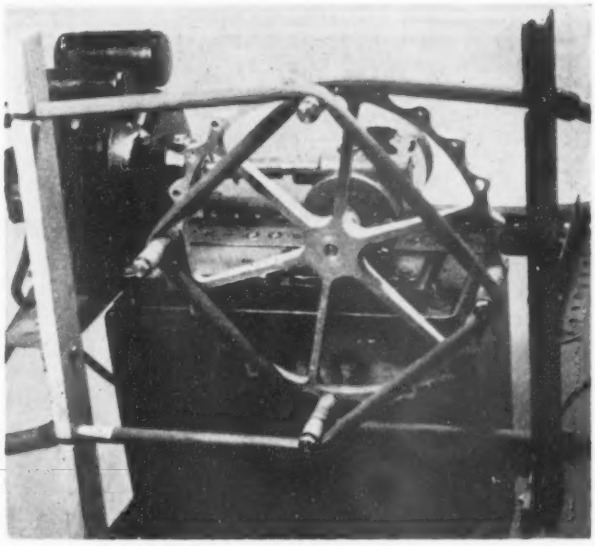

FIGURE 2.—A dual-unit Brittingham squeegee pump. The discharge of one tube may be connected to the intake of the second tube to make a single four-stage unit.

The rotating disc is connected directly to a motorized speed reducer and revolves at a rate of 37 r.p.m. A variable-speed motor and variable-speed reduction could be selected to give different pump characteristics. The tube is subject to more rapid fatigue at greater disc speeds.

When three rollers are used on a disc, the pump may be viewed as a single-stage pump. With four rollers, it is essentially a two-stage pump. Figure 2 shows two tubes supported on opposite sides of a rotating disc. The advantage in this arrangement is that the off-balance forces against the disc shaft have been equalized by adding the second tube pumping in the opposite direction. Then, if the discharge of one tube is connected to the suction of the other, the pump becomes a four-stage unit.

A comparison of the head discharge curves of a Brittingham pump operating under pressure and suction is shown in Figure 3 for an amber rubber tube of ½-in. bore and ⅛-in. wall thickness. The 30-in. piece of tube was stretched to 39.2 in., or 131 per cent of its length. Since 2.28 in. of pressure was included in the suction head curve, it may be noted that the efficiency of the pump decreased rapidly as the suction was increased beyond 3 in. of Hg. However, the pump is self priming, even at a suction head of 14 in. of Hg. This thin-walled tube collapsed quite readily, but, by increasing the wall thickness and using a shorter tube length, the pump suction characteristics can be greatly improved.

The effect of the tautness and the wall thickness on the pump characteristics is shown in Figure 4. Two amber rubber tubes of ¼-in. I.D. and 1/16-in. wall thickness were stretched 143 and 151 per cent of their original length. It may be observed that virtually a constant discharge was maintained by the most taut tube over a total pressure range up to 10 in. of Hg, whereas the less taut tube gave a variable discharge in this range. When an amber rubber tube of the same bore but 3/32 in. in wall thickness was used, the discharge was very constant over a pressure range up to 20 in. of Hg.

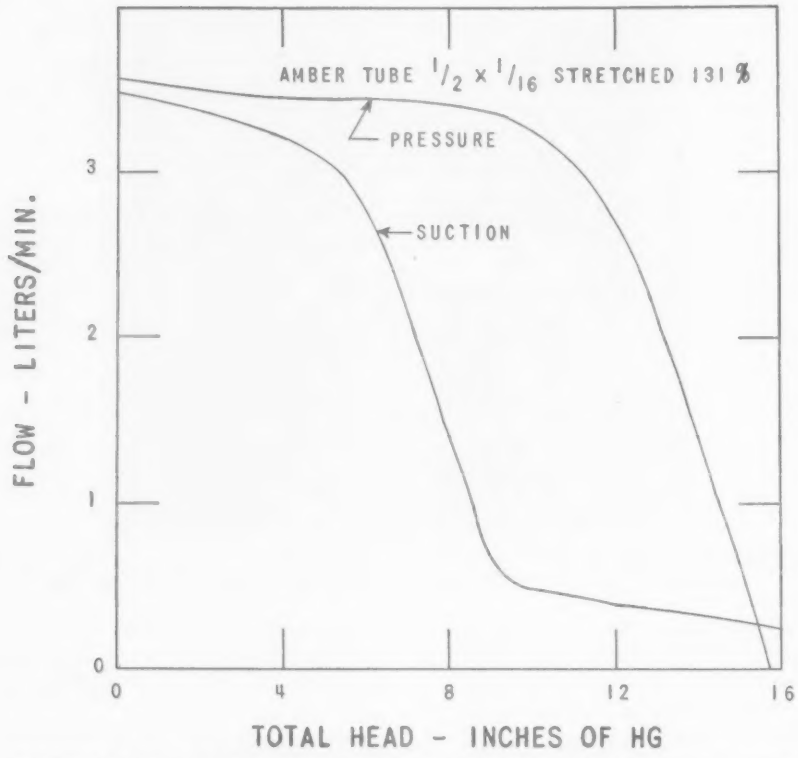

FIGURE 3.—Head-discharge curves for 1/2-in. by 1/16-in. wall thickness amber rubber tube stretched 131 per cent of the relaxed length and squeegeed at a rate of 140 ft. per min.

A combination of disc speed, roller spacing, tube bore, and wall thickness of the tube will produce a great variety of pump characteristics. To estimate requirements for a specific purpose, consider the distance between adjacent rollers on centers to be the "stroke" and the tube bore the diameter of a piston pump. Since the tube is collapsed at the rollers and the bore becomes smaller the more the tube is stretched, the effective capacity of a stroke will be less than the calculated value. The effective capacity can, however, be expressed as a percentage of the calculated capacity. With five amber rubber tubes of different bore and thickness and roller spacing of 6 to 10 in., the effective capacity varied from about 50 per cent of the calculated capacity for small-bore heavy-wall tubes (¼ by $^{3}/_{32}$ in.) to 80 per cent for large-bore, thin-wall tubes (½ by $^{1}/_{16}$ in.), provided the pump was operated on the plateau of the discharge curve.

Summary and Conclusions

The principles of operation and examples of the operating characteristics of the Brittingham laboratory pump have been given. The pump is inexpensive. It is non-clogging, self-priming, and suitable for pumping fluids or gases which do not attack the tubing of rubber or plastic used in the construction. The pump can be constructed as a single- or multi-stage unit and a single- or multi-pump unit. Under proper operating conditions the

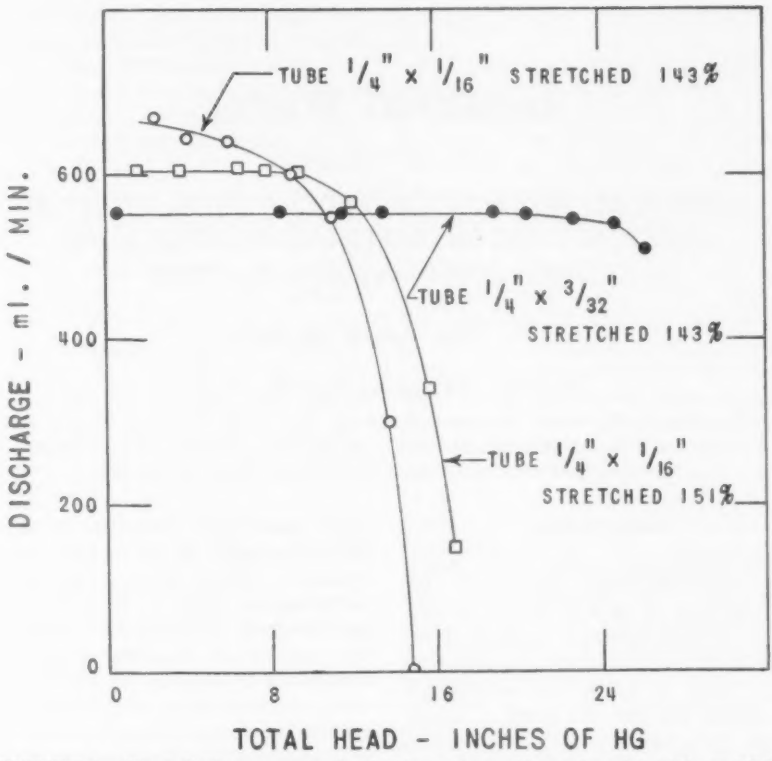

FIGURE 4.—Head-discharge curves for 1/4-in. amber rubber tube with 1/16- or 3/32-in. wall thickness, stretched 143 and 151 per cent of the relaxed length and squeegeed at a rate of 140 ft. per min.

flexible tube, which acts as a piston, has several months of serviceable life and is readily replaceable. Insignificant thermal effects are produced, even when pumping 3.0 per cent sewage sludge. The unit is readily adaptable for use in continuous air, water, or sewage sampling and the feeding of liquid chemicals. The pump is useful for recirculating air through a sample and gas scrubber train as a means of determining the oxygen utilized or the carbon dioxide evolved as a measure of the "quality" or "strength" of activated sludge, industrial waste, and polluted water. With modification, the pump may be used for the metering of small air and liquid flows.

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Industrial Wastes

CRITICAL REVIEW OF LITERATURE ON THE TOXICITY OF INDUSTRIAL WASTES AND THEIR COMPONENTS TO FISH

II. The Metals, as Salts

By Peter Doudoroff and Max Katz

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Introduction

The nature and purpose of this literature review have been discussed in the introduction to Part I (37). As indicated therein, material published before 1910 is not reviewed, as a general rule. Only a few earlier publications of special interest are cited. Unpublished data are reported occasionally, but no attempt has been made to collect and review much of the obtainable unpublished information.

Various metal salts are important constituents of mine effluents, brines from oil wells, and wastes of metal-processing, chemical, and many other industries (21)(42). Most of the metal compounds considered here are those simple inorganic salts the toxicity of which is evidently referable chiefly to the component metals. Other metal salts, such as potassium cyanide and complex cyanides, are to be dealt with in another part (Part III) of this review. It is noteworthy that, in effluents from electroplating (metal finishing) and some other industrial plants, heavy metals may occur in combination with cyanide as complex ions. Discussion of the toxicity of the metal-cyanide complexes, some of which are known to be less harmful to fish than their constituents (18)(93) must follow a discussion of the toxicity of free cyanide. With a few exceptions, metal-organic compounds are not considered here. Comparative studies of the toxicity of different metals, the factors which account for variations of their toxicity, and other matters of general interest are discussed first. The metals are then considered individually, in alphabetical order.

Comparative Studies of the Metals

Comparative studies of the toxicity of metals to fish have been undertaken by several investigators. In the present discussion, a substance is said to be more toxic than another if, after indefinitely prolonged exposure, it can cause death or demonstrable injury at a lower concentration. At high concentrations, the substance which is said to be more toxic may be less rapidly fatal than the other. Therefore, tolerable concentration limits based on tests of very brief duration (for example, 1 hr. or 6 hr.) are not at all reliable indices of relative toxicity as it is defined here. Corresponding average values based on uniform tests continued for at least 1 or 2 days are much less likely to prove seriously misleading.

and are deemed useful (although not invariably accurate) indices of relative toxicity (36). Data based on more prolonged tests are even more satisfactory in this regard. Evaluation of maximum concentrations tolerated indefinitely is desirable, but is not often feasible.

Concentrations of toxicants in industrial wastes and polluted waters usually are reported in parts per million, or milligrams per liter. As a general rule, tolerable concentration limits should be evaluated and expressed accordingly (36). However, this procedure tends to obscure relationships of theoretical interest when the toxicities of metal cations are compared. Therefore, most students of this subject have regarded one gram atom of metal per liter as the most appropriate basic unit of concentration. The choice of different concentration units can, of course, result in somewhat different arrangements of the metals based on their relative toxicity.

The comprehensive studies of Jones (63)(64) are of outstanding importance; therefore, some of his results are presented and discussed first. The compounds tested were mostly nitrates. They were added to a very soft tap water "of a high degree of purity" (calcium content about 1 p.p.m.) The fish used were sticklebacks (*Gasterosteus aculeatus*), usually 30 to 50 mm. in length, but smaller (18 to 20 mm.) in a few experiments. Usually 4 or 5 fish were exposed to 2 l. of each solution tested, and the solution was renewed at daily intervals. A series of 10 to 20 concentrations of each salt was tested in this manner, at temperatures of 14° to 18° C. Most of the results were presented graphically, by plotting only the average survival time of the fish in each solution against the corresponding concentration, and fitting a curve to each set of points so plotted. The concentration of each salt at which the average survival time of the fish was found to be approximately equal to that of controls in tap water was taken to be the "lethal concentration limit."

The average survival time of large sticklebacks (30 to 50 mm. long) used as controls in tap water was only about 10 days. Two lots of small controls (18 to 20 mm. long) survived, on the average, for 25 and 30 days. The reason for the short life of the larger controls is not clear. The fish were not fed during any of the tests, and Jones suggested that this may explain the mortality of controls, but no experimental evidence was presented. Judging by the longevity of other fasting fish at comparable temperatures, one can conclude that death probably was due to some other factors, such as the quality of the experimental water. In any event, the true significance of Jones' "lethal concentration limits" is somewhat obscure. They evidently do not represent limits of concentrations tolerated indefinitely by healthy fish. Nevertheless, the concentrations of salts at which the test fish died much sooner than the controls were unquestionably harmful under the conditions of the experiments.

Some of Jones' results are summarized in Table I. The tabulated concentrations of metals corresponding to different survival times (about 1, 2, 4, and 7 days) are either actual experimental concentrations or values derived by interpolation from Jones' data, using curves which did not in all cases coincide with those fitted by Jones. Jones arranged the metal cations in order of increasing toxicity, or decreasing lethal concentration limits, expressed as "molar concentrations," or as gram atoms of metal per liter, the latter terminology being more explicit. The same arrangement of the metals is shown in Table I. Results obtained with ferric chloride are not included in Table I, because Jones found the toxicity of solutions of this salt to be due to excessive acidity (pH below 5.0). The pH values of the other solutions tested ranged from 6.0 to 6.8, with the exception of solutions

TABLE I.—Metal Concentrations for Various Survival Times of Large Sticklebacks[1]

Metal	Compound Tested	Conc. of Metal (in mg. per liter) at Which Survival Time Averaged About				Lethal Conc. Limit[2]	
		1 Day	2 Days	4 Days	1 Week	(mg./l.)	(g. atoms/l.)
Na	$NaNO_3$	3,000	1,500	800	600	500	2.17×10^{-2}
Ca	$Ca(NO_3)_2$	4,500[3]	3,000	1,500	1,000	800	2.00×10^{-2}
Sr	$Sr(NO_3)_2$	10,000	7,000	3,000	1,500	1,200	1.37×10^{-2}
Mg	$Mg(NO_3)_2$	2,000	1,500	500	350[3]	300	1.23×10^{-2}
Ba	$Ba(NO_3)_2$	3,000	2,500	1,000	500	400	2.90×10^{-3}
K	KNO_3	500	200	100	70	50	1.27×10^{-3}
Mn	$Mn(NO_3)_2$	300	150	100	50	40	7.28×10^{-4}
Co	$Co(NO_3)_2$	150	50	20	15	10	1.68×10^{-4}
Cr	$Cr_2(SO_4)_3$	5.0	2.0	1.4[3]	1.3	1.2	2.30×10^{-5}
Ni	$Ni(NO_3)_2$	10.0	3.0[4]	1.5	1.0	0.8	1.34×10^{-5}
Zn	$ZnSO_4$	1.5[3]	0.9[3]	0.7	0.4	0.3	4.60×10^{-6}
Al	$Al(NO_3)_3$	0.3	0.2[3]	0.13[3]	0.1	0.07	2.60×10^{-6}
Au	$HAuCl_4$	1.5[4]	1.4[3]	1.0	0.6	0.4	2.00×10^{-6}
Cd	$Cd(NO_3)_2$	7.0	3.0	0.7	0.3	0.2	1.78×10^{-6}
Pb	$Pb(NO_3)_2$	1.0	0.7	0.3	0.2	0.1	4.80×10^{-7}
Cu	$Cu(NO_3)_2$	0.3	0.1[4]	0.06	0.02[4]	0.015	2.36×10^{-7}
Hg	$HgCl_2$	0.6[3]	0.45[3]	0.2	0.02	0.008	4.00×10^{-8}
Ag	$AgNO_3$	0.1	0.02[4]	0.01	0.004	0.003	2.80×10^{-8}

[1] Concentrations of metals at which the survival time of large sticklebacks averaged about 1 day (19 to 30 hr.), 2 days (38 to 60 hr.), 4 days (76 to 120 hr.), and 1 week (140 to 200 hr.), according to the data of Jones (63)(64).

[2] Jones' "lethal concentration limits," or concentrations of the metals at which the average survival time nearly equalled that of controls (about 10 days).

[3] Interpolated value; suitable empirical value lacking.

[4] Corresponding values derived by interpolation are greater than the nearest empirical values shown by about 30 to 40 per cent.

of calcium nitrate (pH 6.8 to 8.6) and more acidic solutions containing aluminum, chromium, and gold. Jones was able to show that the toxicity of solutions in which the fish survived for one day or longer, other than those of iron salts, was attributable neither to unfavorable pH nor to excessive osmotic pressure. The pH values of none of these solutions were below 5.0, and HCl solutions with this pH were not demonstrably toxic. Results obtained when zinc sulfate was tested with small sticklebacks were not very markedly different from those shown in Table I. On the other hand, the small fish tolerated for 2, 4, and 7 days at least 3 times as much lead nitrate (about 2.5, 1.0, and 0.6 mg. per l. as Pb) as did the large fish; yet they withstood 0.1 mg. per l. as Pb for only 14 days (average), whereas controls lived for 30 days.

Jones' choice of the nitrates of most of the metals is deemed unfortunate. Nitrate ions are not very toxic to fish, but are never present in high concentrations in natural waters. Data reported by several investigators (58)(62)(108)(148) indicate that the nitrates of sodium and calcium are somewhat more toxic than the corresponding chlorides. It is unlikely that the anions present contributed markedly to the toxicity of very dilute solutions of highly toxic metal salts. The observed toxicity of the solutions of some of the less toxic nitrates may not be attributable entirely, however, to the toxicity of the metallic cations under investigation. Nevertheless, with a few possible exceptions, Jones' data undoubtedly reveal real differences between the toxicities of the metals. An apparent inverse relation between the toxicity and the solution pressure of the metals was discussed by Jones.[1]

[1] This relation had been noted much earlier by Mathews (91), who studied the toxicity

Oshima (99) and Iwao (61) compared the toxicities of the chlorides of numerous metals to young eels and to the very small fresh-water cyprinodont fish *Orizias latipes*, respectively. Only condensed, partial translations of their reports could be used in preparing this review.[2] The nature of the waters used by these investigators could not be determined, and the pH values of the solutions also are not known. Oshima (99) tested the sulfates of some of the bivalent metals, as well as the chlorides, and only the sulfate of nickel was tested. Each salt was tested by exposing 3 to 5 eels, weighing 1.2 to 2.0 g. apiece, to each concentration (molar) of a series (volume of solution unknown; average temperature 20° to 22° C.), and determining their average survival time. The tests of all the metal chlorides were continued for at least 50 hr., whereas those of the sulfates were of somewhat shorter duration. In summarizing his results, Oshima arranged the metal cations in order of decreasing toxicity, grouping together those of nearly equal toxicity, as follows: Hg^{++}, [Cu^{++}, Zn^{++}, Cd^{++}], [Sn^{++}, Al^{+++}, Ni^{++}, Fe^{+++}], Fe^{++}, Ba^{++}, Mn^{++}, [K^{+}, Ca^{++}, Mg^{++}], Na^{+}. The highest concentrations of the chlorides tested which were tolerated by all the fish for more than 50 hr. were: 1×10^{-7} M $HgCl_2$; 1×10^{-6} M $CuCl_2$, $ZnCl_2$, and $CdCl_2$; 1×10^{-5} M $AlCl_3$ and $SnCl_2$; 3×10^{-5} M $FeCl_3$; 1×10^{-4} M $FeCl_2$; 0.0025 M $BaCl_2$; 0.05 M $MnCl_2$; 0.1 M $MgCl_2$, $CaCl_2$, and KCl; and 0.2 M NaCl. Corresponding concentrations of some other salts tested were: 0.01 M KNO_3, 0.0075 M K_2SO_4, 0.0025 M K_2CrO_4, 5×10^{-4} M $K_2Cr_2O_7$, and 5×10^{-5} M $KMnO_4$. Maximum concentrations of some additional salts which were tolerated for more than 25 hr. were: 0.1 M $MgSO_4$; 0.01 M $MnSO_4$; 1×10^{-4} M $NiSO_4$ (31 hr. average); 1×10^{-6} M $AgNO_3$; and 5×10^{-5} M $KFe(SO_4)_2$, $KCr(SO_4)_2$, $KAl(SO_4)_2$, and $NH_4Al(SO_4)_2$; but the next higher concentration tested in each case was 10 times greater. The average survival times in 1×10^{-4} M $ZnSO_4$ and 1×10^{-5} M $CuSO_4$ solutions were about 20 and 21 hr.

Iwao (61) exposed three mature *Orizias* to only 20 ml. of each solution in a 4-cm. diameter glass cylinder and reported lethal concentration limits based on 24-hr. tests. The very small volume of the solutions is not satisfactory, because dilute solutions of heavy metal salts can be quite rapidly detoxified by fish. The metals were arranged in order of increasing toxicity, or decreasing 24-hr. minimum lethal concentration (molar) of the compounds tested, as follows: Na, Mg, Ca, Sr, Li, Mn, K, Co, Ba, Ce, Cd, Pt, Th, Au, Pd, Cu, Hg. The compounds tested and the reported 24-hr. lethal concentration limits were: 0.5 M NaCl (or about 0.25 M, according to a graph); 0.25 M $MgCl_2$; 0.125 M $CaCl_2$ and $SrCl_2$; 0.0625 M $LiCl_2$ and $MnCl_2$; 0.0312 M KCl and $CoCl_2$; 0.0156 M $BaCl_2$; 7.81×10^{-4} M $CeCl_3$; 2.44×10^{-4} M $CdCl_2$; 8.13×10^{-5} M H_2PtCl_6; 4.88×10^{-5} M $ThCl_4$; 4.06×10^{-5} M $HAuCl_4$ and $PdCl_2$; and 2.44×10^{-5} M $CuCl_2$ and HgCl (?).[3] The gold and plati-

of the chlorides of the metals (except Pb and Ag, of which the nitrate and acetate were tested) to fertilized eggs of the mummichog (*Fundulus heteroclitus*) in distilled water. The concentrations of the most dilute solutions which killed all, or nearly all, of about 20 embryos (initially 2- to 8-cell stage) within about 36 hr. were tabulated. The metals can be arranged in order of decreasing molar concentrations of these solutions (only a few of which are shown here in parentheses) as follows: K (0.75 M), Na, Sr, Mg, Ba and Li, Ca, Mn^{++}, Al, Fe^{++}, Co^{++}, Ni^{++} (0.033 M), Zn (6×10^{-4} M), Pb (1×10^{-4} M), Fe^{+++}, Cd, Cu^{++}, Au^{+++}, Ag, Hg^{++} (1×10^{-5} M). This arrangement differs from that of Jones notably with respect to the positions of K, Ca (0.14 M), and Al (0.11 M). Median or average limits of tolerance unfortunately were not evaluated.

[2] The valuable assistance rendered by T. Iwai of the University of Mie, Japan, and S. Soneda of the Public Health Service, Cincinnati, who supplied these translations, is gratefully acknowledged.

[3] A misprint is suspected, as mercurous chloride is not soluble to the extent indicated. $HgCl_2$ may have been tested instead.

num probably occurred as complex anions.

Powers (108) studied the toxicity of a number of metal salts to goldfish. The survival time of at least 2 fish (in 2 l. of solution at a temperature near 21° C.) at each concentration of a series was determined in testing each salt. The lowest concentration tested was not always tolerated for a long time, however, no attempt having been made to determine maximum concentrations tolerated for any uniform prolonged exposure period. The experimental results were presented in tables and graphs; and certain indices of the "relative toxicity" of the salts were computed, the significance of which, in relation to practical considerations, is obscure. Powers (110) reported, also, results of some similar tests of the toxicity of Na, Ca, Mg, and Ba chlorides to bluntnose minnows at several different temperatures (12.8° to 32.8° C.). The most dilute solution of each salt tested was 0.025 M. This concentration sooner or later proved fatal to the minnows in every case. The nature of the water used by Powers (108) (110) was not clearly stated, but there are reasons for believing that a distilled water, perhaps of very poor quality, probably was used. Such a water was said to have been used in another related study of the toxicity of LiCl and NH_4Cl to goldfish (109). It was prepared by condensing steam in a glass tube, but its reported mineral content (residue on evaporation 38 to 42 p.p.m., methyl orange alkalinity 26 to 36 p.p.m., ammonia nitrogen 7.4 to 12.5 p.p.m.) is unusual for distilled water.

Rapid mortality of goldfish in the most dilute experimental solutions of $CuCl_2$ (0.009 p.p.m. as Cu) and $CdCl_2$ (0.001 p.p.m. as Cd) was reported (108). Probable lethality of much more dilute solutions is indicated, as the average survival time of the fish decreased very gradually and irregularly with increasing concentration of these salts. However, the reliability of Powers' unique results can be reasonably questioned pending corroboration. Some unknown lethal or synergistic agent, or other source of error, may have been involved. Ferric chloride proved somewhat less toxic (pH of solutions not reported). Satisfactory comparison of the toxicity of other, less toxic chlorides tested by Powers (Ba, K, Li, Sr, Mg, Ca, Na) is impossible, because of the nature of his data. Relatively high toxicity of Ba ions and low toxicity of Na ions (in dilute, equimolar solutions of the chlorides) are evident, however. The nitrates of Na, Ca, Mg, and Sr appear to be more toxic than the corresponding chlorides.

Powers' own conclusions are not in accord with some of the previous statements. For example, his indices of relative toxicity show the chlorides of Na and Mg (but not of Ca and Sr) to be more toxic than the corresponding nitrates. His conclusions and somewhat involved procedure cannot be detailed here. The same method has been adopted by several other investigators, but its theoretical soundness and practical utility have not been established. Even Powers (108) noted that his measure of relative toxicity, which he described as a "natural criterion," is not universally applicable. When applicable, it still can be very misleading, as it involves an unusual concept of relative toxicities.

Hirsch (58) determined the highest concentrations of several salts, dissolved in tap water, which usually could be tolerated by eels for a long time (more than 6 days). These threshold concentrations were reported to be N/2 NaCl; N/4 $MgCl_2$, $MgSO_4$, and $CaCl_2$; N/8 Na_2SO_4; N/16 $NaNO_3$ and $Ca(NO_3)_2$; and less than N/100 KCl, K_2SO_4, and KNO_3. Three eels were held in 1 l. of solution at summer room temperature. The tests were not entirely uniform, and the results were somewhat erratic and are not all clearly in accord with the author's conclusions. Controls did not live well in the tap water used. Nevertheless,

some of the data reported are instructive.

Garrey (50) exposed minnows (*Notropis blennius*) for prolonged periods to solutions of Na, Ca, Mg, and K chlorides, prepared with distilled water (redistilled in glass). Two or three laboratory-acclimated fish were held in each aquarium (glass finger bowl), containing 100 ml. of solution, which was renewed daily. The total number of fish used in each test was not stated. In a 0.25 per cent (0.043 M) NaCl solution the fish died in 9 to 24 days (average 18 days) at room temperatures. In 0.025 M and 0.0075 M $CaCl_2$ solutions they died in 2 to 4 days and 14 to 21 days, respectively. At the next lower concentration of $CaCl_2$ (0.0025 M) they lived for 5 to 7 weeks (end of experiment). In 0.025 M $MgCl_2$, 0.005 M $MgCl_2$, and 0.005 M KCl solutions the fish lived only for about 2 days, 4 to 6 days, and 12 to 29 hr. (average 24 hr.), respectively. Of 31 fish held in distilled water, 10 died within a week, but the rest survived, without food, until the experiments were discontinued after 3 to 8 weeks. Controls in tap water were held without mortality for more than 2 months. Garrey's data indicate that potassium was decidedly more toxic than magnesium, which was more toxic than calcium; and that sodium was the least toxic of the metals tested (as chlorides).

Wiebe *et al.* (151) determined the average survival time of 3 to 6 golden shiners at each of four lethal concentrations of Na, Ca, and Mg chlorides. The water used was a mixture of distilled and tap waters with pH 7.8 to 7.9. The solutions were held at room temperatures (near 22° C.) and aerated continually. In 5,000 p.p.m. NaCl, $CaCl_2$, and $MgCl_2$ solutions, the survival time averaged 148, 143.5, and 96.5 hr., respectively; and in 10,000 p.p.m. solutions it averaged 97, 27.6, and 4.6 hr., respectively. Differences of molarity and osmotic pressure of the solutions under comparison were not considered.

Edmister and Gray (40) reported the "toxicity thresholds" of $CaCl_2$, NaCl, and KCl for 24 hr.-old fry of whitefish (*Coregonus clupeiformis*) in Lake Erie water to be 22,080, 16,500, and 10,368 p.p.m., respectively. Corresponding values for fry of yellow pikeperch (*Stizostedion vitreum*) of the same age were reported to be 12,060, 3,859, and 751 p.p.m., respectively. The duration of the tests and other experimental conditions were not reported in the brief abstract that apparently is the only published record of the experiments. Abegg (2) (3) reported the 24-hr. median tolerance limits of NaCl, $CaCl_2$, and KCl for bluegill sunfish in a synthetic river water to be 14,100, 8,400, and 5,500 p.p.m., respectively.

Some of the investigators who undertook comparative studies of the toxicity of salts of heavy metals (26) (84) tested very high, rapidly fatal concentrations only. For reasons already indicated, the results of such brief tests are not very instructive. Carpenter (26) reported that the survival time of minnows in 0.1 N solutions of $CdSO_4$, $Pb(NO_3)_2$, $ZnSO_4$, $FeSO_4$, $FeCl_3$, $CuCl_2$, $CuSO_4$, and $HgCl_2$ averaged 180.5, 150, 144, 144, 86, 82.5, 49.5, and 20.5 min., respectively. Léger (84) determined minimum concentrations of salts (sulfates and chlorides of Cu, Zn, Fe, and Al) which proved lethal or evidently injurious within 1 hr. to trout and minnows in both distilled and very hard waters. The reported minimum lethal concentrations ranged from 25 to 4,000 p.p.m. and were mostly above 200 p.p.m.

Other investigators who tested salts of several heavy metals failed to evaluate accurately any comparable indices of their relative toxicity. Ebeling (39) exposed only 1 or 2 rainbow trout for about 2 to 3 days to one or a few concentrations of each salt tested. The solutions (15 to 25 l.) were prepared with aerated tap water (pH 7.6) and

held at temperatures between 16° and 22° C. Schaut (130) also tested only one or a few concentrations of some metal salts dissolved in tap water (80° F.), using "fresh-water minnows (killies)," which were not properly identified. The duration of most of the tests was only 1 hr. Ellis (42) reported the survival times of goldfish at several widely differing concentrations (1,000, 100, 10, and 1 p.p.m.) of various metal salts dissolved in "very soft water" and in "hard water" (carbonate hardness less than 23 p.p.m. and over 98 p.p.m. as $CaCO_3$, respectively). Each fish was held in 3 l. of solution at temperatures between 18° and 23° C., and the tests were continued for at least 96 hr. if the fish did not die sooner. During some of the tests the solution was renewed continually, at the rate of 1 l. per hour, by means of constant-flow apparatus. Some of the instructive data reported by these investigators are presented in another section of this review, where the metals tested are considered individually.

Thomas (141) studied the toxicity of numerous metal salts to the mummichog, or killifish, *Fundulus heteroclitus*, in sea water, as well as in fresh tap water. He decided that aluminum sulfate and lead nitrate could not be tested in sea water, because of the immediate formation of precipitates. The chlorides of cobalt, manganese, and nickel, zinc sulfate, ferric ammonium citrate, and potassium dichromate were reported to be apparently non-toxic in sea water, concentrations up to 200 p.p.m. having been tolerated by the fish for 1 to 2 weeks. On the other hand, mercuric chloride, cadmium nitrate, and cupric sulfate and chloride were reported to be quite toxic in sea water, but their relative toxicities were not indicated.[4] In fresh water, the following concentrations of the salts were reported to have proved fatal within the exposure periods indicated: 3 p.p.m. of lead nitrate in 12 hr.; 4 p.p.m. of copper sulfate in 10 hr.; 6 p.p.m. of cadmium nitrate in 36 hr.; 7 p.p.m. of aluminum sulfate in 5 days, and 14 p.p.m. in 36 hr.; 10 p.p.m. of zinc sulfate in 48 hr.; 12 p.p.m. of manganese chloride in 6 days; and 16 p.p.m. of nickel and cobalt chlorides in 5 days. No marked difference between the lethalities of the chlorides of Mn, Ni, and Co is evident. Apparently, these were the least toxic of the metals tested, whereas lead and copper were the most toxic metals. Thomas failed to indicate whether the concentrations reported were based on weights of the salts with or without water of hydration. Ellis (42) and many other investigators also have been negligent in this respect.

The toxicity of waters that had been in contact with various metals and alloys to fish and fish eggs (embryos) has been studied by Podubsky and Stedronsky (103)(104)(105). Obviously, this is not a reliable index of the relative toxicity of the metals (as salts) in solution. It was reported that contact with copper, brass, nickel-bronze, silver, gold, zinc, and mercury rendered water toxic, whereas manganese, nickel, lead, iron, and pewter had no such effect. Copper and copper alloys were

[4] No reports of more recent, comparative studies with marine fishes have been found. Although much earlier publications generally are not reviewed here, the data of Richet (116) are of sufficient interest to be summarized briefly. He exposed several marine species to varying concentrations of chlorides of various metals dissolved in sea water and reported the following limits of tolerance, in grams of metal per liter, based on results of 48-hr. tests: 24 to 25 g. Na (including the sodium naturally present in sea water), 2.4 g. Ca, 2.2 g. Sr, 1.5 g. Mg, 0.78 g. Ba, 0.3 g. Mn or Li, 0.125 g. Co or Ni, 0.1 g. K, 0.017 g. Cd, 0.014 g. Fe^{+++}, 0.0084 g. Zn, 0.0033 g. Cu^{++}, and 0.00029 g. Hg^{++} per liter. The relatively low value for zinc (8.4 mg. per l.), which Thomas (141) reported to be virtually non-toxic in sea water, is especially noteworthy. The tests of Ba, Sr, and Fe chlorides were performed with treated sea water, from which sulfates and phosphates were said to have been eliminated by the addition of an appropriate amount of barium, without rendering it harmful for the fish.

most effective. Earlier, Marsh (89) stated that contact with copper, zinc, aluminum, and perhaps even tin, can render water toxic to fish. Some of these conclusions need verification.

Antagonism and Synergism of Metal Cations

It has long been known that the toxicity of some metal cations to aquatic organisms is counteracted, or antagonized, by other metal cations in mixed salt solutions (57). A physiologically "balanced" salt solution is one in which different salts, and particularly Na, Ca, K, and Mg ions (the principal cations found in natural waters) occur in such proportions that the specific toxicity of each is neutralized, or reduced nearly to a minimum, through the antagonistic action of the other salts or ions present. Sea water, in which NaCl is the predominant salt, is a balanced salt solution. Loeb and Wasteneys (85) (86), who used mummichogs as experimental material, reported some of the early studies of the antagonism of the principal cations of sea water, relating to fish.

Garrey (50), whose experimental methods already have been described, determined the average longevity of minnows (*Notropis*) in various simple and mixed solutions of Na, K, Ca, and Mg chlorides in distilled water. The following selected data, showing salt concentrations and corresponding average longevities, illustrate the antagonism of some of the cations:

9,000 p.p.m. NaCl (about 0.15 M)	2 days
9,000 p.p.m. NaCl and 0.001 M $CaCl_2$	8–10 days
(Additional $CaCl_2$ produced no more favorable results)	
0.025 M $CaCl_2$ (about 2,775 p.p.m.)	2–4 days
0.025 M $CaCl_2$ and 6,750 p.p.m. NaCl	8–10 days
0.025 M $MgCl_2$ (2,380 p.p.m.)	2 days
0.025 M $MgCl_2$ and 0.01 M $CaCl_2$	6 days
0.005 M KCl (373 p.p.m.)	1 day
0.005 M KCl and 0.0005 M $CaCl_2$	6 + days
0.005 M KCl and 6,175 p.p.m. NaCl	2–3 days
0.015 M KCl (1,118 p.p.m.)	20 hr.
0.015 M KCl and 0.0075 M $CaCl_2$	13 days
0.015 M KCl and 0.005 M $MgCl_2$	3–5 days

It will be noted that relatively small amounts of $CaCl_2$ added to toxic solutions of Na, Mg, and K chlorides markedly reduced their toxicity, as little as 20 to 40 p.p.m. as Ca being highly effective against NaCl and KCl. High concentrations of NaCl counteracted the toxicity of $CaCl_2$ and KCl; and $MgCl_2$ also was antagonistic to KCl. No pronounced reciprocal antagonisms other than the mutual antagonism of NaCl and $CaCl_2$ were demonstrated. However, it was reported that KCl and $MgCl_2$ proved somewhat antagonistic to NaCl-$CaCl_2$ and NaCl-KCl-$CaCl_2$ mixtures, respectively.

Powers (111) also studied the reciprocal antagonism of NaCl and $CaCl_2$, using minnows. Inasmuch as all the solutions tested were unnecessarily concentrated and very rapidly lethal (probably largely because of their high osmotic pressure), his results are not very instructive. However, reduction of the lethality of NaCl solutions by the addition of small amounts of $CaCl_2$ was clearly demonstrated.

Krüger (78), experimenting with sticklebacks (*Gasterosteus aculeatus*), found that 0.35 M and 0.4 M solutions of NaCl alone were rapidly fatal, the median survival time (at 17° to 20° C.) averaging about 2 hr. In 0.4 M mixed salt solutions prepared by adding KCl, $MgCl_2$, $CaCl_2$, or combinations of two or more of these salts to 0.35 M NaCl solutions, the fish invariably lived longer. However, all the mixtures containing no calcium proved more rapidly fatal than a mixture of NaCl and $CaCl_2$ only. Median survival times of fish in the NaCl-$CaCl_2$ solution ranged from 13 to more than 30 days. The best results (median survival time exceeding 6 weeks) were obtained with mixtures of NaCl, $CaCl_2$, KCl, and $MgCl_2$ or $MgSO_4$, and in some (but not all) tests of mixtures of NaCl, $CaCl_2$ and either $MgCl_2$ or KCl. The solutions were all prepared with distilled water (redistilled in glass) and made neutral by the addition of $NaHCO_3$. Ten fish were used in each test, and

most of the mixtures were tested 2 or 3 times.

Other investigators have noted also that mixed (physiologically balanced) salt solutions were less harmful than simple NaCl solutions with corresponding osmotic pressures to sticklebacks (55)(56), stickleback larvae (115), hatching salmon eggs (114), etc. River water softened by the zeolite process, whereby Ca ions are replaced with Na ions, has been reported to be toxic to trout (94)(95). It was rendered nontoxic, however, by adding to it as little as 3.3 per cent of the hard (unsoftened) river water, or the equivalent of less than 10 p.p.m. $CaCO_3$. Young (155) has given further consideration to antagonism and balance of the principal cations found in natural waters, with reference to fish.

Some metals which are highly toxic to fish in distilled and soft natural waters have long been known to be much less toxic in hard water (84) and in sea water (141). The relatively low toxicity of heavy metals in highly mineralized waters can be due to factors other than cation antagonism, such as the formation of precipitates, which is discussed elsewhere. For this reason, the important role of cation antagonism sometimes has been overlooked.

Ellis (42) reported that, in solutions prepared with distilled water and containing 10 p.p.m. of cupric sulfate, the survival time of goldfish averaged 150 min. in the absence of other salts (pH 4.0); 180 min. in the presence of 500 p.p.m. of sodium nitrate (pH 5.7); 400 min. in the presence of 5,000 p.p.m. of sodium nitrate, which was the optimum concentration (pH 6.0); and 765 min. in the presence of 5,000 p.p.m. of sodium nitrate and 50 p.p.m. of calcium chloride (pH 6.4). Salt antagonism is indicated. Considerable difference of the pH of the experimental solutions, for which no reason was stated, is a complicating factor. Results of some experiments with bluntnose minnows performed by the senior author of this review (unpublished data) indicate, however, that calcium salts, such as $CaSO_4$, are indeed antagonistic to $CuSO_4$. Ellis and Ladner (45) reported that the toxicity of copper salts is counteracted also by magnesium salts, but no experimental data were presented.

Jones (63) determined the survival time of sticklebacks in solutions of lead nitrate (0.4 and 1.0 p.p.m. as Pb) prepared with very soft tap water (calcium content about 1 p.p.m.) to which varying amounts of $CaCl_2$ (0 to 50 p.p.m. as Ca) had been added. The average survival time increased with increasing $CaCl_2$ concentration until it equalled that of controls (about 10.5 days). For example, in solutions containing 1.0 p.p.m. Pb with 0, 5, 10, 20, and 50 p.p.m. of added calcium, the survival times averaged about 1, 3, 6, 7, and 10.5 days, respectively. It was reported that exactly the same results were obtained when calcium nitrate in chemically equivalent (equimolar) amounts was substituted for the chloride. Goldfish, which were killed in 60 to 114 hr. by 10 p.p.m. Pb in the soft water, survived for at least 15 days when this amount of lead and also 50 p.p.m. of calcium were added to the water (as nitrates), 2 of 5 goldfish surviving for 35 days. In similar experiments in which $ZnSO_4$ and $Ca(NO_3)_2$ were used, sticklebacks usually tolerated 2 p.p.m. Zn with 50 p.p.m. Ca for 10 days, although 2 p.p.m. Zn without added calcium proved fatal in about 18 hr. In the presence of 50 p.p.m. Ca, sticklebacks exposed to 1 p.p.m. Pb or 2 p.p.m. Zn, and goldfish exposed to 10 p.p.m. Pb, showed no symptoms of respiratory distress. The rate of respiration remained nearly normal until a short time before death, and no film of coagulated mucus was found on the gills. The experimental solutions remained clear, whereas solutions of the metal salts without added calcium were rendered cloudy by precipitated mucus. It was reported also that 0.5 ml. of 1

per cent $Pb(NO_3)_2$ solution added to 20 ml. of clear filtered slime from the body of a large eel caused precipitation and coagulation of the mucus; but when 5 ml. of 1 per cent $Ca(NO_3)_2$ solution had been previously added to the slime, no precipitation of mucus occurred on addition of lead. Similar results were obtained in tests with $ZnSO_4$. The action of lead on the mucus was not reversed by subsequent addition of calcium. Fish affected by lead nitrate recovered no more rapidly in tap water with added calcium than in soft water. It was concluded that calcium somehow prevents the precipitation of mucus by the heavy metal salts. The cause of death of fish in solutions of these salts is discussed elsewhere in this review.

Although some metal cations are antagonistic to more toxic heavy metal cations, some of the heavy metals are synergistic, mixed solutions of their salts being much more toxic than simple solutions of corresponding concentrations. Bandt (11) reported that the toxic effects of the sulfates of Zn and Cd and of Ni and Co in mixed solutions of two salts were merely additive. The toxicity of mixtures of the sulfates of Ni and Zn, and especially of Cu and Zn and of Cu and Cd, on the other hand, was much more intense (up to 5 times greater) than it would have been if the toxic effects of the metals were simply additive. The solutions were prepared with distilled water or, more often, with mixtures of tap and distilled waters. The experimental fish were trout and roach. Unfortunately, the procedure was not detailed, and experimental data were not presented. Very pronounced synergism of cupric and zinc sulfates, dissolved in soft water, has been reported also by Doudoroff (35). Minnows (*Pimephales*) usually withstood for 8 hr. 8.0 p.p.m. of Zn alone and 0.2 p.p.m. of Cu alone; but most of them succumbed within 8 hr. in a mixed solution containing only 1.0 p.p.m. Zn and 0.025 p.p.m. Cu.

Hydrolysis and Precipitation of Metal Compounds

Aqueous solutions of some metal salts, such as chlorides, nitrates, or sulfates of Al, Fe, Cr, Sn, Mn, Cu, Pb, etc., are markedly acidic, because of partial hydrolysis. When one of these salts is added to an alkaline natural water, precipitation of a nearly insoluble hydroxide or basic salt of the metal may occur. Until enough of the salt is added to neutralize the natural alkalinity of the water and to increase the hydrogen ion concentration sufficiently so that further precipitation does not occur, the concentration of metal remaining in solution thus is limited. It can vary, however, with the pH and the free CO_2 concentration, the CO_2 liberated through decomposition of bicarbonates in the water tending to hold some of the metal in solution.

It has been reported that in a hard, alkaline water (total alkalinity about 150 p.p.m.) very high concentrations of copper sulfate (up to 150 p.p.m. $CuSO_4 \cdot 5H_2O$) were tolerated by young black bass, the insoluble basic copper carbonate formed in hard water being "non-injurious to fish" (153)(147). Such reports can be very misleading, and their significance should be carefully considered. It is noteworthy that the experimental solutions were artificially aerated during the tests (153). Such aeration, whereby liberated CO_2 is removed (raising the pH value), can result in rapid precipitation of copper, which otherwise would remain in solution. Had the solutions not been aerated during the tests in question, concentrations of copper sulfate reported to be harmless to bass probably would have proved fatal to these fish.[5]

[5] Some pertinent observations (unpublished data) have been recorded by the senior author of this review. Bluegill sunfish lived for 6 days in a soft well water of very high alkalinity (due to the presence of $NaHCO_3$) to which 500 p.p.m. $CuSO_4 \cdot 5H_2O$ had been added, and which was aerated for 1.5 hr. before the introduction of the fish (when the pH was

Furthermore, a more sensitive species may be unable to tolerate the very small amount of dissolved copper that can remain in solution in an alkaline water. Obviously, the precipitation of any copper present in addition to this fatal quantity cannot protect the sensitive fish very effectively against injury by dissolved copper. It has been reported that a high concentration of copper sulfate (25 p.p.m.) is less rapidly fatal for trout fry in very alkaline water, in which most of the copper is rapidly precipitated, than in water of very low alkalinity (147). However, no evidence has been found in the literature that sensitive fish, such as trout, can live indefinitely in any water containing even a small amount of the precipitate in suspension. Black bass and other members of the sunfish family have long been known to be relatively resistant to copper (97).

Evaluation of the concentration of metal remaining in solution in water in which precipitation of a metal compound has occurred is not always a simple matter. Removal of the precipitate by ordinary filtration, followed by chemical analysis of the filtrate, may not be a satisfactory procedure. Some of the precipitates (such as colloidal basic copper carbonate) are not fully retained, even by fine filter papers, whereas dissolved metal may be retained on the filter by adsorption (22). High-speed centrifuging apparently is preferable to filtration, but there is evident need for more refined techniques for the evaluation of concentrations of metals in solution. For the reasons indicated, some determinations reported in the literature (125)(96) are not deemed reliable.

Investigators who have attributed the lethality of metal salt solutions to the direct harmful action of metal cations or precipitates often have failed to report the pH values of the solutions. Yet, the lethality of some solutions of salts which hydrolyze extensively may be due to the resultant acidity. Liberated CO_2 also can be a lethal agent in solutions prepared with hard waters. Solutions of any strong acid with pH below 5.0, and even less acidic solutions of free CO_2, can be fatal to fish (37).

Jones (64) reported that sticklebacks held in a tap-water solution of $FeCl_3$ containing 1 p.p.m. of iron at pH 5.0 lived as long as controls held in soft tap water (about 10 days average). In more concentrated $FeCl_3$ solutions, with lower pH values, death was much more rapid, the survival time averaging about 3 days at pH 4.6 (1.5 p.p.m. Fe), 2 days at pH 4.4 (2.0 p.p.m. Fe), 1 day at pH 4.2 (3 p.p.m. Fe), 6 hr. at pH 3.8 (7 p.p.m. Fe), 3 hr. at pH 3.4 (20 p.p.m. Fe), and so forth. There was no significant difference between mortality rates in these solutions and in solutions of HCl with corresponding pH values. It was concluded that the toxicity of the $FeCl_3$ solutions was due mainly or entirely to their acidity, and that the relative toxicity of ferric ions could not, therefore, be evaluated. A generally similar result was said to have been obtained with $FeSO_4$, but details were not reported. It was stated that the $FeSO_4$ solutions, which initially were only slightly acidic, rapidly became highly acidic and turned yellow or brown, because of the formation of H_2SO_4 and $Fe(OH)_3$ through hydrolysis and oxidation. The lethality of these solutions was again at-

7.9) and continuously thereafter. When the same solution was tested without any aeration (pH 6.45), bluegills introduced 15 min. and 3 hr. after its preparation died in 110 min. and 115 min., respectively (mean survival times of 3 fish). In another experiment, 208 p.p.m. $CuSO_4 \cdot 5H_2O$ and varying amounts of HCl were added to the alkaline water and the mixtures were aerated. Only 6 of 10 bluegills survived for 10 days in a mixture with pH 7.1 (after aeration). In each mixture with a higher pH value (pH 7.6, 8.0, and 8.4 after aeration) all of 10 bluegills were still alive after 10 days; and in more acidic mixtures (pH 6.5, 6.1, and 5.0) all died within 6 hr. A pronounced influence of aeration and of small variations of pH on the toxicity of $CuSO_4$ solutions thus was demonstrated.

tributed to their acidity. On the other hand, dilute solutions of $Al(NO_3)_3$ and $Cr_2(SO_4)_3$ with pH values between 5.0 and 6.0 proved fatal to sticklebacks in about 1 to 6 days (average survival times). Inasmuch as HCl solutions with the same pH values were not demonstrably harmful, the toxicity of these salt solutions was not attributable primarily to their acidity. Hydrogen ions may have intensified the toxicity, but the influence of pH on the toxicity of metals in solution has received little attention.

Insoluble metal compounds other than hydroxides and basic salts (for example, $BaSO_4$ and AgCl) sometimes are precipitated upon the addition of metal salts to natural waters. The formation of precipitates usually results in inactivation of toxic metals involved. It has been claimed that some of the precipitates, such as $Fe(OH)_3$, are directly injurious, clogging the gills of fish and interfering with their respiration (84) (134) (127) (46). Convincing evidence that mechanical injury by such suspended matter can be a primary cause of fish mortality is lacking. The accumulation of suspended matter on the gills often appears to be a consequence of damage caused by dissolved toxic substances.

Phillips (101) found that trout were better able to withstand brief therapeutic exposures to a high concentration of copper sulfate (333 p.p.m.) in distilled water, or in hatchery water acidified with acetic acid, than in plain hatchery water. The precipitate formed in the hatchery water, but not in acidified and distilled waters, was believed to contribute to the clogging of gills and the danger of suffocation. There is no evidence, however, that the lethality of less rapidly fatal, alkaline $CuSO_4$ solutions can be overcome by acidification. On the contrary, $CuSO_4$ usually is more harmful to fish in slightly acidic water than in alkaline water in which a precipitate forms.

Mode of Action of Metal Salts and the Role of Anions

The lethality of some physiologically balanced but excessively concentrated salt solutions for fish may not be attributable to the specific toxicity of any of their components. Most fresh-water fishes are unable to maintain nearly normal composition (salt content) of their body fluids in a strongly hypertonic (that is, osmotically much more concentrated) medium, such as sea water. In this respect they differ from marine fishes and those occurring in both fresh and salt water (euryhaline fishes), which have the necessary adaptive mechanism. All cations and anions present in a balanced solution contribute to its osmotic pressure and may, therefore, contribute also to its lethality for fresh-water fishes that cannot tolerate the osmotic pressure. It is noteworthy, however, that metal cations are not all entirely equivalent with reference to their osmotic action on living cells, some being more effective than others (57).

The freezing point (or its depression below that of pure water) for the normal blood of fresh-water fishes, which is a measure of its osmotic pressure, has been reported to be in the neighborhood of $-0.5°$ C. (15) (49) (131). Garrey (50) found that in diluted sea water with approximately corresponding osmotic pressure, or freezing point lowering, minnows (*Notropis blennius*) were able to live indefinitely (more than 6 weeks).[6] Dilutions of sea water with considerably higher osmotic pressures always proved fatal. Gueylard (56) reported that the survival time of 3 kinds of

[6] This general statement can be made in spite of a discrepancy between results indicated by Garrey in his Tables II and III. Because of this discrepancy, which may be due simply to error, it is not clear just which concentration was the highest that was tolerated for more than 6 weeks. In pure NaCl solutions with freezing points near $-0.5°$ C. (0.76–0.9 per cent NaCl), the survival time averaged only 2 to 4 days.

minnow (*Cyprinopsis, Leuciscus, Gobio*) in diluted sea water with a freezing point (depression of − 0.6° C.) averaged only 6 to 8 days. Perch (*Perca fluviatilis*) lived as long at a slightly higher salinity, and the euryhaline stickleback (*Gasterosteus leiurus*) was not affected at all by a salinity 3 times as great as that which killed the minnows in about 6 to 8 days. Tests of lower salinities with minnows and perch were not continued for much longer periods, so that salinities tolerated indefinitely by these fish were not determined.

Some authors have concluded that the salinity of diluted sea water and similar brines (balanced salt solutions) with osmotic pressure equal to that of the blood is critical for fresh-water fishes. This generalization has been widely accepted, and Ellis (42) believed that it is applicable even to solutions of NaCl in river water of medium hardness. There is some evidence, however, that it is erroneous or misleading. The available cryoscopic data indicate that the concentrations of sodium chloride solutions corresponding to the normal bloods of fresh-water fishes with respect to osmotic pressure are generally between 8,000 and 9,000 p.p.m. NaCl. The corresponding concentrations of sea salts are only slightly different. It has been reported that some hardy fresh-water fishes, such as goldfish, can withstand indefinitely, or for long periods, salinities as high as 14,000 to 15,000 p.p.m. (15)(107)(145). On the other hand, Pora (106) reported that, excepting relatively small individuals of 3 species, fresh-water fishes of 5 kinds (*Cottus, Cobitis, Gobius, Leuciscus, Barbus*) could not tolerate for 12 days a balanced solution of salts from artificial sea water with a salinity of only 4,000 p.p.m. Individuals weighing about 20 g. survived about 2 days (*Cottus*) to 10 days (*Barbus*). Relatively large individuals of each species were decidedly less resistant than small ones. Even a salinity of 2,000 p.p.m. was not always tolerated. Unfortunately, the ability of marine or euryhaline species to live in a much more concentrated solution of the same salts (artificial sea water) was not demonstrated.

Osmotic dehydration of the tissues of fresh-water fish dying in hypertonic saline media has been reported often. However, their death may be due primarily to any one of several possible causes. As indicated previously (37), the causes of death of fish in variously polluted waters and pertinent observations are not considered fully in this review. Black (15) has reviewed recent literature on the osmotic regulation of teleost fishes and the effects on fresh-water and euryhaline fishes of saline waters, with especial reference to sea water.

The action of some of the highly toxic heavy metals has been investigated by Carpenter (24)(26)(27), Behrens (12), Ellis (42), Jones (62)(63)(64)(67), Westfall (149), and others. All the investigators named agree in attributing the death of fish in solutions of salts of the heavy metals studied (Pb, Zn, Cu, Hg) chiefly to the coagulation or precipitation of mucus secreted by the gills, or damage to gill tissues. Insoluble metal-protein compounds formed are believed to interfere with the respiratory function of the gills, and thus to bring about death by suffocation. Carpenter (26) detected no lead in the bodies of fish which had been killed in solutions of lead nitrate and then washed thoroughly with dilute acetic acid and distilled water. Most of the lead initially present in the experimental solutions to which the fish had been exposed was recovered from the washings, which contained the metal in combination with mucus. However, Behrens (12), who used a radioactive isotope as a tracer, noted some penetration of lead into internal tissues of fish held in solutions of the chloride. Ellis (42) presented evidence that the circulation of blood through the gills, as well as

the flow of water over the gills, can be interfered with by the precipitated mucus, which clogs the gills and immobilizes the gill filaments. He believed that direct damage to gill tissues, due to precipitation of proteins within the cells, also may be involved.

Jones (63) (67) found that the breathing rate (frequency of opercular movements) of fish increased sharply in toxic solutions of $Pb(NO_3)_2$, $ZnSO_4$, $CuSO_4$, and $HgCl_2$. It remained abnormally high until the fish were returned to tap water, or until a short time before death, when it fell rapidly. The rate of oxygen consumption, on the other hand, fell gradually until death, after an initial increase due probably to stimulation of activity (67). Carpenter (26) also noted an increase of the respiratory rate of minnows in lead salt solutions, and a decrease of the rate of CO_2 production. Westfall (149) found that the ability of goldfish to withstand exposure to a very high concentration of lead nitrate (5 g. per liter) was markedly impaired at low dissolved oxygen concentrations. All fish survived for 2 hr. in the presence of 6.2 p.p.m. of dissolved oxygen, whereas all died within 2 hr. when the oxygen concentration was 1.4 p.p.m., although a lower concentration (0.9 p.p.m.) had no effect in the absence of lead.

The cause of death of fish at low, barely fatal concentrations of toxicants cannot always be safely inferred from the results of experiments involving exposure to relatively high, rapidly lethal concentrations only. The irregular form of some of the concentration-longevity curves plotted by Jones (64) suggests that the action of some of the metal salts tested by him (for example, $Mg(NO_3)_2$ and $HgCl_2$) may not be quite the same at all lethal concentrations.

Dawson (30) found evidence of injury to blood cells of catfish exposed for long periods (16 to 183 days) to a 50-p.p.m. solution of lead acetate in tap water, which was renewed at 48-hr. intervals. This and other histological evidence of chronic lead poisoning (changes in organs) indicated slow absorption of lead, possibly from the gastrointestinal tract. The solution used did not prove fatal to the fish, although pronounced anemia was produced. The absorption of much copper by fish exposed to solutions of $CuSO_4$ in sea water has been reported by White and Thomas (150). The absorbed copper was found in the blood and other internal tissues. The absorption of nickel, which was said to be virtually non-toxic in sea water, from sea-water solutions of $NiCl_2$ also has been reported (142). It is noteworthy that the ingestion of much water by marine and euryhaline fishes is an essential part of their osmoregulative process when they are in sea water (136).

The harmful action of some metal salts which do not coagulate mucus undoubtedly is wholly internal or intracellular, following penetration of the metals into the tissues, which has been shown to occur (87). Krüger (78) presented pertinent results of a detailed study of the cause of death of sticklebacks in pure (unbalanced) NaCl solutions. Abegg (2) (3) reported recently some interesting observations having to do with the effects of various salts (NaCl, KCl, Na_2SO_4, Na_2CrO_4, $Na_2Cr_2O_7$, etc.) on bluegill sunfish. Krauss (77) reported other histological studies of the action of K, Na, and Ca salts on fish. The roles of hydrogen ions and of precipitates formed in solutions of some other metal salts (such as $FeCl_3$) already have been considered.

The toxicity of metal salt solutions is not, of course, entirely independent of the anions present along with metal cations. Some anions are decidedly toxic. Chromate and permanganate ions (which are themselves partly metallic) are among these. The low toxicity of mixed, physiologically balanced solutions of metal chlorides (NaCl and $CaCl_2$, etc.) is evidence,

however, that chloride ions are relatively harmless, even when compared with ions of sodium, the least toxic of the metals. The specific toxicity of NaCl alone is evidently attributable to Na ions. It has been noted already that nitrate and sulfate ions apparently are somewhat more toxic than chloride ions, but the difference is not very pronounced. It is concluded that the toxicity of non-hypertonic solutions of all but a few metal chlorides, sulfates, and nitrates, and many other metal salts also, is referable mostly, or entirely, to specific toxicity of the metal cations. It is assumed that the metals in the solutions usually are present or effective chiefly as free metal cations, although it is realized that there probably are exceptions, the importance of which cannot yet be reliably estimated (135). Complex ions can have distinctive physiological properties (65)(35), and the role of anions which enter with metals into their formation can be important in this respect.

Jones (62) ascribed the toxicity of solutions of heavy metal salts to the metal cations, but presented evidence that "at the same molar concentration the sulfates of heavy metals are much less toxic than the nitrates and chlorides." When the survival time of sticklebacks was plotted against the normality of the experimental solutions, the resulting curves for the different salts of the same metal (Zn, Cu, or Ni) diverged widely. When the survival time was plotted against the product of normality and conductance ratio, on the other hand, the resulting curves nearly coincided. It was concluded that "the factors responsible for the lower electrical conductivity of the sulfate also lower the chemical activity of the sulfate so that the toxicity falls in proportion to the conductivity." It is noteworthy, however, that all of Jones' plotted data show survival of the fish in the experimental solutions for only about 300 min. or less. The data are so plotted that satisfactory comparison of maximum concentrations of the different salts tolerated for relatively prolonged periods is not possible. Inasmuch as the conductance ratio approaches unity with increasing dilution, it appears that, if the mathematical relation noted by Jones holds at all concentrations, very dilute equimolar solutions of the different salts of a very toxic metal should not differ markedly in toxicity. Accordingly, minimum demonstrably toxic concentrations of these salts, expressed as p.p.m. of the metal, should be nearly equal, unless some unknown or unusual factors invalidate the extrapolation and the application of Jones' data.

Léger (84) also reported the chloride of zinc to be much more toxic than the sulfate at high concentrations, especially in distilled water. Carpenter (26), on the other hand, reported that minnows were killed more rapidly by $CuSO_4$ than by $CuCl_2$ in 0.01 N solutions. In view of the high salt content of sea water, a pronounced real difference between comparable dilute solutions of these salts in sea water, such as that reported by Thomas (141), would be difficult to explain. He stated that copper sulfate apparently was much less toxic than the chloride.

No convincing evidence has been found that the role of anions of soluble salts of the most toxic metals, such as chlorides, sulfates, and nitrates of copper, zinc, etc., is often important in a practical sense. Their influence on the toxicity of very dilute solutions should be investigated further. However, in natural waters polluted with these salts, various anions present initially usually predominate, the concentrations of added anions being relatively low when gross pollution is not involved. In such mixtures the added salts lose their identity. Anions associated with metal cations of relatively low toxicity certainly may not be disregarded, however. The toxicity of various anions to fish is to be considered in another part (Part III) of this review.

Miscellaneous Considerations

The results reported in the literature of tests on the toxicity of metal salts to fish are extremely variable. The lack of uniformity is attributable largely to differences of the relative resistance of fish species used, and of the dissolved mineral and gas content of the water, the influence of which already has been discussed. The duration of exposure obviously is another important variable. The differences between short-term and long-term tolerance limits are more striking with some of the heavy metal salts than with many other toxicants. Jones (63) found that 0.4 p.p.m. of zinc killed sticklebacks in soft water in about 6 days (average), and 2 p.p.m. Zn killed them in about 18 hr.; yet 20 p.p.m. Zn could be tolerated for nearly 6 hr., and 200 p.p.m. could be tolerated for more than 2 hr. (average 143 min.). Léger (84) reasoned that pollution which does not prove harmful within 1 hr. is negligible, because of dilution which occurs thereafter in flowing streams, and because fish which are not overcome soon can escape from polluted water. Other authors recently have favored only slightly more prolonged exposure periods such as 6 hr. (59)(81)(82)(83)(146). Yet, discharges of pollutants are not always intermittent and of brief duration. Furthermore, Jones (68)(69) and others have shown that fishes do not always avoid waters polluted with metal salts and other toxicants, and seem to be attracted by lethal concentrations of some of these pollutants.

Some other factors that may influence the toxicity of metal salts to fish, and account for some of the variability of experimental results reported here, are discussed next herein. When experimental data are evaluated, compared, or applied, these considerations are important.

Temperature

Temperature has been shown to have a very pronounced influence on the survival time of fish in lethal solutions of metal salts, such as the chlorides of Li, Na, Ca, Ba, and Mg (109)(110) and lead nitrate (26). The average survival time usually decreases with rising temperature, being often reduced by well over 50 per cent when the temperature is increased by 10° C. Maximum metal concentrations tolerated indefinitely are not necessarily always much greater at low temperatures than at higher temperatures, at which the action of the toxicants is accelerated. There is need for investigation of the relationships in question. However, there are reasons for believing that concentrations which are not demonstrably toxic to fish at moderate experimental temperatures often may be quite rapidly fatal at high temperatures which are otherwise harmless.

Purity and Formula Weights of Chemicals Tested

The toxicity of some experimental solutions of metal salts may have been due largely to unknown impurities. Some of the chemicals used, in early investigations especially, may have been much less pure than the best analytical reagents now obtainable. Highly toxic impurities obviously can be especially troublesome when they are associated with salts of relatively low toxicity. In this connection, it is interesting to note that, according to Oshima (99), young eels were killed more rapidly by 0.65 mg. of zinc per liter than by 5,493 mg. of manganese per liter (0.1 M $MnCl_2$ solution); and that 0.1 mole of reagent grade manganous salt ($MnSO_4 \cdot H_2O$) which meets current American Chemical Society specifications (9) may contain well over 1 mg. of zinc (limit 0.01 per cent).

There is uncertainty, also, regarding concentrations of solutions tested by many investigators. The concentrations of salts often have been reported ambiguously in parts per million (or mg. per liter), without specifying formulas or formula weights on which

the values were based. There are good reasons for believing that both concentrations of hydrated salts commonly used as reagents (such as $CuSO_4 \cdot 5H_2O$) and concentrations of the same salts without water of hydration have been so reported. Some authors apparently have made unjustifiable assumptions concerning the significance of values previously reported in the literature, thus aggravating an already confused state of affairs. One can only hope that in the future investigators will be less negligent when reporting experimental data.

Volume of Experimental Solutions

Carpenter (24)(26)(27) noted that the toxicity of dilute solutions of lead salts apparently could be reduced by reducing the volume of the solutions, or by increasing the size of the fish exposed thereto. Also, the toxicity could be increased by renewing the solutions periodically. The survival time of fish killed successively in the same solution increased progressively, showing that the solution was becoming less toxic. It was concluded that the concentration of active free lead in a limited volume of experimental solution is reduced rapidly through its combination with the mucus of the fish. When the volume of a demonstrably toxic solution in which a fish is held is less than a certain critical volume (which varies with the size of the fish), and the solution is not renewed, the fish thus is able to detoxify the medium completely and to survive indefinitely. For example, minnows lived for 13 days in 500 ml. of unrenewed lead nitrate solution containing 1 p.p.m. Pb; whereas the same concentration of lead, and even 0.4 p.p.m. Pb, proved fatal in about 2 days, or sooner, when the solutions were renewed 7 to 11 times during the tests (24). In pure water or in detoxified solutions, fish which had withstood exposure to toxic solutions of lead salts were able to shed the coagulated mucus (which rendered the medium turbid) and to recover completely. Dilling *et al.* (33) claimed that daily renewal of experimental solutions of lead nitrate (1,000 ml. per fish) did not accelerate the lethal action on goldfish. The evidence presented was meager, however. Carpenter (26) argued that to be effective the renewal of the solutions must occur at intervals of time which are insufficient for complete detoxification of the solutions and shedding of the film of coagulated mucus from the gills.

The foregoing conclusions apparently are applicable also to salts of highly toxic heavy metals other than lead, which combine with mucus. The toxicity of such salts to fish, evaluated experimentally without frequent renewal of solutions in small aquaria, can be much less than their toxicity under conditions insuring uniformity of concentration.

Acclimatization

It is well-known that euryhaline fishes and some fresh-water fishes are better able to withstand a gradual increase of the salinity of their medium than a corresponding abrupt increase (15)(145)(56). Accordingly, fishes which have been gradually acclimatized may do well in saline waters which are rapidly fatal after sudden transfer from fresh water. Little evidence of such acclimatization of fish to metal salt solutions other than sea water and similar brines (more or less balanced mixtures) has been found in the literature. Hirsch (58) presented some experimental evidence of acclimatization of eels to high concentrations of calcium salts, but concluded that there was little or no acclimatization to chlorides and sulfates of sodium and magnesium. His results are not deemed conclusive.

It has been suggested that acclimatization may account for the survival of fish in certain waters contaminated with zinc (51)(4) and copper (100), but the evidence presented is incomplete and unimpressive. Affleck (4) reported that rainbow trout fingerlings

which did not die of zinc poisoning after having been transported in a galvanized iron can (treated with aluminum paint) withstood such transportation much better than did fish which had not been previously exposed to zinc-contaminated water. Selection of relatively resistant fish by the initial treatment may account for some of the reported difference of survival percentages. Furthermore, only one such experiment was reported, and there is no assurance of absolute uniformity of the dissolved zinc concentrations involved, as the fish were not transported in the same can. Paul (100) stated that the concentration of copper in some polluted streams in California is sufficiently high to prevent introduction of hatchery-raised fish, although the resident population is apparently acclimated. However, hatchery-bred fish may be less tolerant than wild fish of the same species. Although convincing experimental evidence of acclimatization of fish to salts of the highly toxic metals is lacking, the adaptive faculties of fishes deserve attention and thorough investigation.

Toxicity of Metals Considered Individually

In this section, the metals are discussed in alphabetical order, with primary attention to lowest concentrations of their chlorides, sulfates, and nitrates reported to have proved toxic to fish. Relatively high concentrations which have been tolerated for fairly prolonged periods also are noted. Pertinent experimental data presented in the foregoing sections are not fully reported and discussed again herein. Some conclusions based on these data are presented, however, with references. The experimental methods of Jones (63)(64), Oshima (99), Iwao (61), Powers (108)(110), Garrey (50), Ebeling (39), Ellis (42), and other authors whose work is cited repeatedly here are described in the section on comparative studies of the metals. Some papers which have not been considered previously are reviewed here, and data or conclusions derived from other publications are briefly summarized. Finally, the attention of researchers is directed to "additional references," or sources of relevant data which there has been no occasion to mention in the course of the brief discussion of a metal under consideration. A few unimportant metals mentioned heretofore (Au, Pt, Ce, Th, Pd), concerning the toxicity of which, as salts, there is little available information, are not considered further in this section.

It will be noted that in most instances minimum toxic concentrations of metals reported by Jones (63)(64) are the lowest, or among the lowest, of the demonstrably toxic concentrations mentioned. The principal reasons for this should be kept in mind. Jones' experiments, which already have been discussed fully, involved the use of very soft tap water with unusually low mineral content, and his tests were more prolonged than those of most of the other investigators. It should not be assumed that the sticklebacks used by Jones in most of his tests are exceptionally sensitive fish. On the contrary, there is evidence that these fish are comparatively resistant. For this and other reasons, one must conclude that even Jones' data probably do not reveal minimal concentrations of metals which can be toxic to sensitive fish under adverse conditions.

Aluminum

Jones' data (64) show that aluminum nitrate can be toxic to fish in very soft water at concentrations near 0.1 p.p.m. as Al (at pH 6.0 to 6.2). The toxicity of dilute solutions evidently was not attributable to their acidity. Generally similar results were said to have been obtained also with aluminum sulfate and potassium aluminum sulfate.

Minkina (96) reported that, in solutions prepared by adding varying amounts of aluminum chloride to tap

water (pH 7.2 to 7.4), concentrations of dissolved aluminum (determined after filtering the solutions to remove precipitates) above 0.5 p.p.m. were fatal to various fishes, including goldfish. The pH values of the lethal solutions, and the amounts of $AlCl_3$ added to the water in order to render it toxic, were not reported, however. Oshima (99) noted that young eels were killed in 3.6 hr. (average) in a solution of $AlCl_3$ containing 2.7 p.p.m. of aluminum (pH unknown), but tolerated 0.27 p.p.m. Al for 50 hr. Ebeling (39) reported that in aluminum sulfate solutions prepared with tap water, 1 p.p.m. Al had no effect on a rainbow trout in 48 hr., whereas 5 p.p.m. Al (at pH 6.8) caused a trout to turn over in 5 min. The significance of this unusual observation is not clear. Thomas (141) stated that 7 p.p.m. of the sulfate in fresh water killed mummichogs in 5 days.

Sanborn (127) reported that young bluegill sunfish, black bass, and goldfish (2 of each) tolerated for 7 days 100 p.p.m. of aluminum sulfate (at pH 5.6) in tap water of moderate hardness. The solution was renewed continually by means of constant-flow apparatus. In tests with bass and goldfish without renewal of solutions the same result was obtained, but 250 p.p.m. of the salt proved lethal in 8 to 24 hr. (at pH 4.5). Ellis (42) found that 1,000 p.p.m. of potassium aluminum sulfate in hard water killed goldfish in 1 to 10 hr. (at pH 5.5); 100 p.p.m. killed some, but not all goldfish in 12 to 96 hr. (at pH 6.8); and 10 p.p.m. killed none in 96 hr. (at pH 7.6). The solutions were renewed continually.

Pulley (113) observed that 44 p.p.m. of aluminum chloride added to sea water killed no fish in 11 to 14 days; 88 p.p.m. killed all but one of several marine species in 30 min. to 9 days; and 132 to 176 p.p.m. killed all the fish within 4 days. The pH of the lethal solutions increased gradually, during one of the tests, from pH 4.5–5.0 to pH 6.5–7.0 in 125 hr. Their toxicity decreased as they aged, but sea water to which 176 p.p.m. of aluminum chloride had been added was reported to have remained toxic after standing for 193 hr. and becoming nearly neutral in reaction. The evidence presented is scanty, however. A curious explanation of the observed gradual changes of pH (perhaps due simply to the escape of liberated CO_2) was presented.

Additional references: (84) (89) (91) (130).

Arsenic

Arsenic is a transitional element, or metalloid, which is sometimes classed as a metal. Its common compounds do not belong, however, to the classes of compounds with which the foregoing general and comparative discussion has to do primarily. Their toxicity will be considered in another part (Part III) of this review.

Barium

Jones' data (64) show that barium nitrate can be toxic to fish in soft water at concentrations in the neighborhood of 500 p.p.m. as Ba. Considerably lower concentrations of barium may well be deemed hazardous for sensitive fish, although concrete evidence of their lethality has not been found in the literature. Oshima (99) reported that the survival time of young eels averaged only 36 hr. at a barium chloride concentration of 1,374 p.p.m. as Ba (at 20° C.). Powers' data (110) indicate that 1,720 p.p.m. Ba (in $BaCl_2$ solutions) can be fatal to minnows in less than 9 hr. at temperatures below 15° C., and much sooner at higher temperatures.[7] Jones' sticklebacks, on the other hand, were able to withstand 2,500 p.p.m. Ba for about 2 days (average at 15° to 18° C.).

[7] The "velocities of fatality" reported by Powers (110) are erroneously defined in that paper as "survival time over 100"; but, as indicated in an earlier paper to which reference is made (109), the correct definition obviously is "100 over the survival time in minutes."

Additional references: (52) (61) (91) (108) (116).

Cadmium

The data of Jones (64), who tested the nitrate, show that cadmium salts can be decidedly toxic to fish in soft water at concentrations in the neighborhood of 0.3 p.p.m. as Cd. This conclusion is confirmed by results of the senior author's experiments with cadmium sulfate and fathead minnows (unpublished data). Much lower concentrations also may be dangerous in some waters. Powers' experimental evidence that 0.001 p.p.m. of cadmium in a solution of the chloride killed goldfish in 8.7 to 18 hr. and that lower concentrations may be fatal after more prolonged exposure (108) is noteworthy, but needs verification. Oshima (99) reported that the average survival time of young eels at a $CdCl_2$ concentration of 1.12 p.p.m. as Cd was 18.4 hr. (at 21° C.) It should be noted that the cadmium concentration tolerated for about 18 hr. by Jones' sticklebacks (at 15° to 18° C.) was much greater (10 p.p.m. Cd). Thomas (141) reported that 6 p.p.m. of cadmium nitrate in tap water proved fatal to mummichogs within 36 hr., and that this salt is highly toxic to the same fish also in sea water.

Additional references: (11) (19) (26) (61) (91) (116).

Calcium

The data of Garrey (50), Powers (110), and Jones (64) indicate that calcium chloride and nitrate, when added to distilled or soft waters, can be toxic to fish at concentrations between 300 and 1,000 p.p.m. as Ca. Other available data (2) (3) (31) (40) (58) (61) (99) (108) (148) (151) reveal the lethality (more or less acute) only of higher concentrations of calcium salts (usually $CaCl_2$) in various waters. The survival of fish for 1 to more than 3 days at concentrations equivalent to more than 2,500 p.p.m. Ca (sometimes over 4,000 p.p.m. Ca) has been reported by most of the investigators.

Additional references: (16) (17) (77) (84) (91) (116) (154).

Chromium

Jones' data (64) show that chromic salts (trivalent chromium) can be toxic to fish in soft, slightly acidic water at concentrations near 1.3 p.p.m. as Cr (at pH 6.0), and that 2 p.p.m. of the sulfate, as Cr, can be fatal in less than 2 days (at pH 5.7). Oshima (99) reported that the survival time of young eels in a solution of $KCr(SO_4)_2$ averaged 18.7 hr. at a concentration of 5.2 p.p.m. as Cr (pH unknown). Only one other study of the toxicity of trivalent chromium (sulfate) to fish (83) has been found in available literature. The duration of exposure having been only 6 hr., the minimum fatal concentration for minnows in distilled water was found to be near 40 p.p.m. Cr (pH unknown).

The toxicity of chromates and dichromates, which belong to a class of compounds quite different chemically and toxicologically from typical heavy metal salts discussed heretofore, has been investigated more frequently. The toxicity of these hexavalent chromium compounds is not, of course, referable to simple chromium ions.

Grindley (53) evaluated the toxicity of potassium chromate and dichromate to yearling rainbow trout in continuously aerated distilled water. The relation between the concentration of each salt and the mean exposure time before the fish lost their equilibrium (turned over) was determined (at 18° C.) and represented graphically. When the chromium content of the solutions was 20 p.p.m. (the lowest tested) the resistance time averaged 60 hr. in the chromate solution (75 p.p.m. K_2CrO_4) at pH 6.6, and 72 hr. in the dichromate solution (57 p.p.m. $K_2Cr_2O_7$) at pH 5.5. It was concluded that the limiting concentrations below which these salts would not be toxic

appear to be only slightly below 20 p.p.m. as Cr. Solutions of the two salts with chromium concentrations of 50 p.p.m. were almost equally effective (in about 33 hr.) Much more concentrated K_2CrO_4 solutions proved more toxic than the slightly alkaline $K_2Cr_2O_7$ solutions of equal chromium content, probably because of their extreme acidity (pH 4.1 to 4.7). Unfortunately, nothing was said about the longevity of any controls in the distilled water. Few of the fish which turned over in any of the toxic solutions recovered on transfer to fresh water. Trout probably are no more resistant to chromic salts than sticklebacks, and it appears that in very soft water (at pH near 5.7) hexavalent chromium is much less toxic to fish than trivalent chromium.

Oshima (99) found that in 0.01 M K_2CrO_4 and 0.005 M $K_2Cr_2O_7$ solutions (520 p.p.m. as Cr) the survival time of young eels averaged 12.4 and 5.35 hr., respectively; whereas 0.0025 M K_2CrO_4 and 0.0005 M $K_2Cr_2O_7$ solutions (130 p.p.m. and 52 p.p.m. as Cr) killed no eels in 50 hr. His data indicate that $K_2Cr_2O_7$ is slightly more toxic than K_2CrO_4, but much less toxic than $KCr(SO_4)_2$ (trivalent Cr) in comparable solutions of equal chromium content. Ellis (42) reported that in hard water goldfish were not affected after more than 4 days by 100 p.p.m. of "chromic acid" (52 p.p.m. as Cr) at pH 7.3, nor by 100 p.p.m. $K_2Cr_2O_7$ (35.4 p.p.m. Cr) at unspecified pH; whereas 200 p.p.m. of "chromic acid" (at pH 6.4) and 500 p.p.m. $K_2Cr_2O_7$ proved fatal in 60 to 84 hr. and in 3 days, respectively. Rushton (122) found that a 6-hr. exposure to 100 p.p.m. of $K_2Cr_2O_7$ proved fatal to trout within 12 hr. after their return to fresh water. Abegg (3) reported that the 24-hr. median tolerance limits (that is, concentrations lethal to 50 per cent of test animals in 24 hr.) for bluegill sunfish in a synthetic river water of average hardness were found to be 930 p.p.m. for Na_2CrO_4 and 728 p.p.m. for $Na_2Cr_2O_7$ (at 21° C.). Thomas (141) reported that mummichogs tolerated 200 p.p.m. of $K_2Cr_2O_7$ in sea water for a week or longer.

Klassen *et al.* (73) studied the toxicity of chromium wastes from an electroplating plant, diluted with very hard water (total hardness 294 p.p.m.), to several fish species, mostly of the sunfish family. The authors apparently believed that the toxicity of these wastes was due only to their hexavalent chromium content (180 to 362 p.p.m.), but their data do not clearly support this assumption. It was suggested that differences of temperature may account for the extreme variability of results obtained when supposedly comparable dilutions (with nearly equal chromium concentrations) of different waste samples were tested. In view of the small temperature differences involved, this explanation appears to be quite inadequate. In one test, all of 10 bluegill sunfish tolerated for more than 10 days 83 p.p.m. Cr at 69° F. and pH 8.2 (average), whereas in another test all of 6 bluegills died within 4 days in a diluted waste sample containing 75 p.p.m. Cr at 71° F. and pH 8.2.[8] Some of the other test results were even more discrepant. The pH of undiluted samples ranged from 4.0 to 6.4, and their ammonia nitrogen content from 0 to 30 p.p.m. It must be concluded that the observed mortality of fish may not have been due to chromium poisoning only, and that the erratic experimental results do not necessarily indicate maximum tolerable concentrations of hexavalent chromium. The data presented show, however, that fishes of the sunfish family could tolerate in hard water as much as 68 p.p.m. Cr for at least 5 days (sometimes much longer), and 45 p.p.m. Cr for at least 20 days.

Additional references: (34) (52).

[8] According to a private communication from one of the authors, the chromium concentrations shown in the figure wherein the data are presented graphically are not "CrO_4" equivalents, the legend being erroneus in this regard. As indicated correctly in the text of the paper, these values represent p.p.m. of chromium.

Cobalt

The data of Thomas (141) and Jones (64) show that salts of cobalt (chloride and nitrate) can be toxic to fish in fresh water at concentrations between 7 and 15 p.p.m. as Co. Other investigators have demonstrated the toxicity of much higher concentrations only. The 24-hr. lethal concentration limit for $CoCl_2$ reported by Iwao (61) is equivalent to about 1,840 p.p.m. of cobalt. Ellis (42) found that 1,000 p.p.m. of cobaltous chloride in both hard water (pH 7.8) and very soft water (pH 6.2) killed goldfish in about 30 hr. (30 to 31 and 28 to 29 hr.) The pH values of the solutions were 7.2 and 6.6. In the very soft water 100 p.p.m. of the chloride killed some goldfish after 168 hr., but others survived longer at this concentration (at pH 6.5).[9] Ebeling (39) reported only that 1 p.p.m. Co in tap water did not affect a rainbow trout in 56 hr. Thomas (141) found 200 p.p.m. of cobalt chloride to be apparently non-toxic to mummichogs in sea water.

Additional references: (11) (91) (116).

Copper

The data of Powers (108) and Jones (63) (64) indicate that cupric chloride and nitrate can be toxic to fish in distilled and soft waters at concentrations between 0.01 and 0.02 p.p.m. as Cu. That this is true also of cupric sulfate is shown by results of the senior author's experiments with fathead minnows in soft water (unpublished data). However, Powers' evidence that 0.009 p.p.m. of copper alone can kill goldfish in only 3.5 to 7 hr. (which suggests lethality also of much lower concentrations) needs confirmation.

The toxicity of copper sulfate to fish in all kinds of natural waters has been studied by many investigators, because of the wide use of this chemical as an algicide, and for other reasons. It is believed that concentrations of this salt usually have been reported in p.p.m. of the hydrated salt, $CuSO_4 \cdot 5H_2O$, but most authors have failed to make their meaning quite clear. Concentrations between 0.1 and 0.8 p.p.m. (probably 0.025 and 0.2 p.p.m. as Cu) have been reported to be either tolerable or harmful (but presumably near the limits of tolerance) in different waters for the following kinds of fish: Trout (71) (124); perch (90) (71); goldfish, carp, suckers, catfish, and pickerel (71); yellow and white perch (in soft lake water with pH 6.0) (28); sheepshead, bluegill sunfish, silver bass, garpike, and catfish (in hard lake water) (112). Concentrations of copper sulfate ranging from 1.0 to 4.0 p.p.m. (or from 0.25 to 1.0 p.p.m. as Cu) also have been reported to be lethal or maximum safe concentrations for the following fishes: Brook trout (90) (13); rainbow trout (39); black bass and sunfish (71); mummichogs (in fresh water) (90); pikeperch, yellow perch, and pickerel (143); goldfish and catfish (in hard water with pH near 7.8) (42); and "minnows" (130). Marsh and Robinson (90) reported that largemouth black bass were killed within 24 hr. by 10 p.p.m. of copper sulfate, but were not killed in 5 days by 5 p.p.m. Much higher tolerance limits for these fish also have been reported (153) (152) (147). For an unspecified period of time 4-in. bass withstood 150 p.p.m. of copper sulfate in hard lake water with a total alkalinity of about 150 p.p.m. (153). The minimum lethal concentration was said to be about 160 to 200 p.p.m. for these fish, and 80 p.p.m. for bass fry averaging 1 in. in length. The experimental solutions were aerated with dispersed air. It has been noted earlier in this review that even 500 p.p.m. $CuSO_4 \cdot 5H_2O$ can be tolerated by resistant fish when the solutions are prepared with very alkaline water and aerated to

[9] This result was reported on p. 414 of Ellis' paper (42). Elsewhere in the same paper (p. 422) the same result was said to have been obtained with a concentration of 10 p.p.m. of the salt, but this statement probably is erroneous.

drive off the liberated CO_2, most of the copper being precipitated.

The duration of tests whereby the previously mentioned critical concentrations of copper sulfate were determined was sometimes 2 to 8 days (90) (39) (42); but in other instances it was only 24 hr. (13) (28) (130), or was not stated at all by the investigators. The natural water used, and other experimental conditions of major import, usually have been described very incompletely, or not at all. Therefore, it can be concluded only that in most of the natural fresh waters of the United States copper sulfate concentrations below 0.025 p.p.m. as Cu evidently are not rapidly fatal for most of the common fish species. Concentrations below 1.0 p.p.m. as Cu, on the other hand, can be quite rapidly fatal to fish in many (and perhaps most) of these waters, but higher concentrations may be tolerated by resistant species (such as black bass) in sufficiently hard, alkaline waters. Factors influencing the toxicity of the salt already have been discussed. Lists of maximum safe concentrations for different fish species, such as those of Moore and Kellerman (97) (71), have been cited again and again in various treatises on water treatment, and handbooks, such as Lange's "Handbook of Chemistry" (79), etc., without adequate qualifying discussion of their significance. It is evident such data cannot be generally applicable and can be very misleading.

Catt (28) and Smith (138) (139) reported some interesting observations made on lakes in which fish populations were almost completely destroyed by the application of copper sulfate, at a rate of about 3 p.p.m. Thomas (141) stated that copper sulfate proved toxic for mummichogs in sea water, but 30 p.p.m. apparently could be tolerated for about 4 days, although 4 p.p.m. killed these fish within 10 hr. in fresh water.

Additional references: (6) (7) (11) (26) (35) (61) (62) (67) (68) (84) (88) (89) (91) (99) (101) (103) (104) (116) (134) (137) (140) (150).

Iron

Very little is known about the toxicity of iron salts to fish, although it has been investigated frequently. The available data raise many questions and provide few definite answers. Some investigators have reported that about 1 p.p.m. of iron, or even much lower concentrations, can be fatal for fish, whereas others have been unable to demonstrate its toxicity.

Jones (64) ascribed the toxicity of solutions of both ferric chloride and ferrous sulfate in very soft water to their acidity. He reported that solutions with tolerable pH values were not demonstrably harmful. Most of the other investigators apparently attributed the lethality of experimental solutions of ferric salts (chloride and sulfate) to iron in some form, but presented no evidence clearly supporting this view. Minkina (96) added varying amounts of $FeCl_3$ to slightly alkaline tap water (pH 7.2 to 7.4). She reported that concentrations of dissolved iron above 0.2 p.p.m., determined after removal of precipitated ferric hydroxide by filtration, proved fatal to several fresh-water fishes (including goldfish). However, the pH values of the lethal solutions and the minimum amount of $FeCl_3$ required for rendering the water toxic were not reported. The pH values of ferric salt solutions tested by other investigators (26) (29) (39) (84) (99) (108) (123) also are not known. Clark and Adams (29) reported that only 0.1 p.p.m. Fe in a distilled-water solution of ferric sulfate (and also 1.28 p.p.m. Fe in a solution of ferrous sulfate) killed certain fish within 24 hr. Hydrolysis of so little ferric sulfate could not have yielded much free acid, but this early observation is unique and needs confirmation. Ellis (42) found that 100 p.p.m. of ferric chloride in hard water (at pH 5.5) and 10 p.p.m. in very soft water (at pH 5.0) did not kill goldfish in 4 days, whereas 100

p.p.m. in the soft water (at pH 3.4) proved fatal within 80 min. An HCl solution with pH 3.5 (prepared with hard water) was almost as rapidly fatal. Much ferric chloride evidently can be tolerated in some well-buffered waters when the hydrogen ion and free CO_2 concentrations are not increased thereby to lethal levels.

Solutions of ferrous sulfate with harmless pH (pH 6.4) have been reported fatal for goldfish (1,000 p.p.m. in hard water fatal in 2 to 10 hrs.) by Ellis (42), and also for black bass and bluegill sunfish (100 p.p.m. in tap water fatal in 2.5 to 7 days) by Sanborn (127). However, 100 p.p.m. of the salt (at pH 6.7 and 6.4) did not kill goldfish in 4 days (42) and 7 days (127), and 50 p.p.m. (at pH 6.6) did not kill bass and bluegills in 7 days (127). The solutions were renewed continually during the tests by means of constant-flow apparatus, but may not have been equally fresh at all times. In the absence of complete experimental records, one can only assume that the reported pH values persisted and that dissolved oxygen concentrations remained adequate throughout the tests. Schaut (130) reported that dissolved oxygen fell in 1 hr. from 92 to 16 per cent of saturation (at 80° F.) in a 17-p.p.m. solution of ferrous sulfate ($FeSO_4 \cdot 7H_2O$), because of oxidation of the ferrous iron. So much oxygen could not have combined with so little iron (3.5 p.p.m.), and this observation consequently is deemed unreliable. Nevertheless, the instability of such solutions is noteworthy. The pH values of ferrous salt solutions tested by most of the investigators who reported lethal or threshold concentrations (13)(26)(29)(38)(99) are not known. Dyk (38) reported that 100 p.p.m. of ferrous sulfate affected no fish; 1,000 p.p.m. killed very young carp in 48 hr., but did not prove toxic for most of the fresh-water fishes used (in winter); and even 10,000 p.p.m. killed tench only after a week, although other species were killed within one day. Belding (13) reported that 133 p.p.m. was the lowest concentration that killed brook trout within 24 hr.

Sanborn (127) stated that the accumulation of ferric hydroxide on the gills appeared to be the cause of death of fishes in ferrous sulfate solutions. The same or similar views have been held by other investigators who studied experimentally the toxicity of various iron salts alone (84) and in combination with other metals (70)(134), or observed the effects of iron-bearing mine effluents on fish in receiving streams (10)(11)(46). Schmidt-Nielsen (134) claimed that iron hydroxide precipitated in diluted solutions of iron salts can cover the gills of fishes and cause suffocation when the concentration of iron is only 2 p.p.m. Even smaller amounts of the hydroxide in a "nascent state" were said to be harmful, the solutions (or suspensions) becoming less harmful on stabilization. Bandt (10) reported that 0.9 p.p.m. of dissolved iron found in well-aerated contaminated waters which were nearly neutral in reaction (pH 6.5 to 7.5) caused mortality and disappearance of fish. Lower concentrations (0.3 to 0.7 p.p.m.) apparently had no effect. Bandt (11) believed that less dissolved iron can be tolerated in nearly neutral water than in more acidic water. He attributed its lethality to the precipitation on the alkaline mucus of the gills of iron hydroxide, which not only obstructs the gills but also injures the gill tissues by corrosive action. Schäperclaus (128)(129) offered the same explanation, but stated that he found concentrations of iron only above 1.9 p.p.m. (at pH 6.7) to be harmful for pike and tench (129).

More recently, Laroze (80), who studied the mortality of trout in a hatchery water contaminated with drainage from a mine with large pyrite deposits, arrived at somewhat different conclusions. He decided that the mortality was caused by about 1 p.p.m. of iron in the water, but could be attributed neither to precipitated iron

hydroxide nor to Fe ions. Only basic iron salts, probably in a semi-colloidal state, were held to be so injurious, and capable of penetrating and damaging the gill tissues. It was asserted that the composition of the water, and above all its pH value between 5 and 6, made possible the existence of the iron in the harmful state. No analytical procedure was proposed for determining how much of the iron present occurs, or is likely to occur, in the dangerous form. Only the effects of this iron could be demonstrated through "microchemical examination" of the gill tissues of fish exposed to the contaminated water. Treatment of the tissues with 10 per cent HCl, and then with potassium ferrocyanide solution, produced a diffuse blue coloration, which was detectable microscopically. The author asserted that the iron within the gill tissues could thus be readily distinguished from harmless superficial deposits.

Much additional research directed toward reliable identification of injurious forms or compounds of iron, evaluation of their lethality, and accurate definition of conditions under which they occur and can persist in polluted waters, evidently is needed. Some of the divergent views and seemingly discrepant observations mentioned can be reconciled through properly designed experiments.

Additional references: (75) (76) (91) (116) (121) (141).

Lead

The data of Jones (63) and of Carpenter (24) (26) show that lead salts can be decidedly toxic to fish in distilled and soft waters at concentrations between 0.1 and 0.4 p.p.m. as Pb. Carpenter's observations were made in the laboratory and also in the field, where fish were held in cages immersed in river water polluted by lead mines. Concentrations of dissolved lead ranging from 0.3 to 0.4 p.p.m., in distilled and river waters (both with pH 6.4 to 6.6), proved fatal to minnows, sticklebacks, and trout. Minnows (*Leuciscus*) were killed in 26 to 48 hr. by 0.4 p.p.m. Pb in solutions of lead nitrate and lead acetate prepared with non-toxic distilled water and renewed 9 times during the test (24). Goldfish proved more resistant. Jones (63) stated that goldfish appeared to be able to tolerate indefinitely 1 p.p.m. (but not 10 p.p.m.) of lead in very soft tap water, in which 0.1 to 0.2 p.p.m. Pb proved fatal to sticklebacks. Minnows (*Phoxinus*) and sticklebacks were not visibly affected after exposure for three weeks to 0.7 p.p.m. Pb in a continually renewed solution of lead nitrate prepared with harder tap water (said to contain about 51 p.p.m. of calcium as calcium bicarbonate). No precipitate was visible in this solution, but when more lead salt was added to the water, a precipitate was gradually deposited in the mixing chamber of the constant-flow apparatus.

Ellis (42) reported that some (but not all) goldfish were killed within 4 days by 100 p.p.m. of lead nitrate (62.6 p.p.m. Pb) in a continually renewed solution (pH 6.8) prepared with hard water (pH 7.8). A 10-p.p.m. lead nitrate solution (pH 7.4) killed no fish in 4 days, whereas 1,000 p.p.m. proved rapidly fatal (at pH 6.4).

It has been reported also that 3 p.p.m. of lead nitrate in fresh water killed mummichogs in 12 hr. (141); that 10 p.p.m. killed trout in 2 hr. (123); that 1 p.p.m. as Pb in tap water did not kill trout in 48 hr. (39); that 17 p.p.m. as Pb was the minimum lethal concentration for goldfish in water of unspecified nature (33); and that varying concentrations up to 4 p.p.m. Pb in running sea water had no clearly demonstrable effect on the development of plaice embryos (33). Catfish withstood 50 p.p.m. of lead acetate in tap water for many days, but became anemic (30).

The possibility of cumulative poisoning of fish with insoluble lead sulfide was suggested by results of experiments with goldfish (42). These died

after 61 days in aquaria with bottoms covered with lead ore, whereas all controls survived. Carpenter (24) failed to demonstrate, through laboratory and field tests lasting 6 weeks or longer, any injurious effect on fish of small particles of galena suspended in the water or deposited on the bottom.

Additional references: (12) (23) (25) (27) (43) (62) (67) (69) (89) (91) (116) (149).

Lithium

The data of Powers (108) (109) and Iwao (61) show only that lithium chloride, at concentrations between 320 and 620 p.p.m. as Li, can kill fresh-water fish in about 1 day, or much sooner (especially at high temperatures). Powers (109) reported 320 to 400 p.p.m. as Li to be very rapidly fatal to goldfish at moderate temperatures, although earlier (108) he reported that these fish survived for an average of 24.5 hr. in a more concentrated solution (617 p.p.m. as Li). Much lower concentrations presumably can be fatal for sensitive fish after prolonged exposure.

Additional references: (91) (98) (116).

Magnesium

The data of Garrey (50), Powers (110), and Jones (64) show that magnesium chloride and nitrate can be toxic to fish in distilled and tap waters at concentrations between 100 and 400 p.p.m. as Mg. However, concentrations of magnesium salts (chloride, sulfate, and nitrate) between 1,000 and 3,000 p.p.m. as Mg often have been tolerated for 2 days, and for longer periods up to 11 days, by fresh-water fishes in various waters (58) (64) (99) (108) (151); and a higher 24-hr. lethal concentration limit has been reported (61). Some fresh-water fish have been found in very saline lake waters containing over 1,000 p.p.m. of magnesium, as well as much sodium and calcium (60).

Additional references: (91) (116) (154).

Manganese

Jones' data (64) show that manganous nitrate can be toxic to fish in soft water at concentrations equivalent to about 50 p.p.m. of manganese. Thomas' observation (141) indicates that only 6 p.p.m. of manganese, or less, also can be fatal when the chloride is added to fresh water, although this salt was not found to be markedly toxic for mummichogs in sea water. On the other hand, Oshima (99) and Iwao (61) found the toxicity of $MnCl_2$ (also $MnSO_4$) for fish in fresh water to be relatively slight. Their results indicate 24-hr. lethal concentration limits near 5,500 p.p.m. as Mn (99) and 3,400 p.p.m. as Mn (61), and Oshima reported that no eels were killed in 50 hr. by more than 2,700 p.p.m. Mn. Jones' sticklebacks, on the other hand, were killed in about 24 hr. by only 300 p.p.m. Mn (64). Kaemmerer and Erichsen (70) reported that 50 p.p.m. Mn, in a tap-water solution of $MnSO_4$, did not kill sticklebacks within 3 days. The serious discrepancy of some of the experimental results mentioned above suggests the need for further investigation. Thomas' finding, especially, cannot be accepted without corroboration, as no results of confirmatory tests of different concentrations were reported by him. High concentrations of dissolved manganese can persist at any pH up to 7.5, there being no precipitation of $Mn(OH)_2$. The lethality of manganese salt solutions to fish cannot, therefore, be attributed generally to precipitation of the hydroxide on the gills, to which the death of fish has been ascribed by Schäperclaus (129).

The permanganates, which belong to an entirely different class of compounds, are more toxic than the manganous salts discussed above. Oshima (99) reported that a concentration of $KMnO_4$ equivalent to 4.1 p.p.m. Mn killed young eels in about 8 hr. (average). Belding (13) reported that 6.25 p.p.m. $KMnO_4$ (2.2 p.p.m. as Mn) killed brook trout within 24 hr. Ellis (42)

stated that 10 p.p.m. $KMnO_4$ (3.5 p.p.m. as Mn) killed goldfish in hard water in 12 to 18 hr.

Additional references: (91) (116).

Mercury

Jones' data (64) show that mercuric chloride can be toxic to fish in soft water at concentrations near 0.01 p.p.m. as Hg. Uspenskaya (144) found that 0.01 p.p.m. Hg in solutions of $HgCl_2$, and also in solutions of $HgSO_4$ and $HgNO_3$ (which are known to be quite unstable), killed minnows (*Phoxinus*), but only after exposure for 80 to 92 days. In solutions containing 0.02 p.p.m. Hg, the fish died in about one month (44 to 47 days in $HgSO_4$ solutions; 19 to 32 days in the others). At concentrations equivalent to 0.1 and 0.05 p.p.m. Hg, mercuric chloride killed the fish in about 8 hr. and 1 day, respectively, and the other salts in about 2 to 6 days. All the solutions were renewed daily. When not renewed, $HgCl_2$ solutions proved less toxic; and solutions prepared with unpurified river water were less toxic than those prepared with clear, purified tap water. Solutions of mercuric oxide and suspensions of powdered calomel proved highly toxic.

Ellis (44) found that in a somewhat alkaline water (pH 7.7 to 7.8) goldfish were killed within 6 days by 1.0 and 0.5 p.p.m. $HgCl_2$ (0.74 and 0.37 p.p.m. Hg). All goldfish (10 or more) tolerated 0.1 p.p.m. $HgCl_2$ (0.074 p.p.m. Hg) for 10 days. Belding (13) reported that the lowest concentration of $HgCl_2$ which proved fatal to brook trout within 24 hr. was 12.5 p.p.m. The significance of this unusual and probably misleading observation is uncertain. Rushton (120) stated that 10 p.p.m. of $HgCl_2$ killed rainbow trout in 15 min.

Jones (65), using minnows (*Phoxinus*), and Binet and Nicolle (14), using sticklebacks, studied the influence of NaCl upon the toxicity of $HgCl_2$ in rapidly lethal solutions prepared with glass-distilled water and with tap water. Small amounts of NaCl, up to 250 p.p.m. at least, had little or no effect. Jones concluded that the formation and ionization of double or complex chlorides of mercury and sodium upon addition of NaCl does not alter the toxicity of solutions of $HgCl_2$, which was said not to ionize in simple solutions. The not inconsiderable dissociation of $HgCl_2$, and that of the complex anions, in the very dilute solutions involved evidently had not been given thorough consideration. In the presence of much NaCl (added to distilled water), Jones found the toxicity of $HgCl_2$ decreasing markedly as the NaCl concentration increased to about 8,700 p.p.m. Glucose, in solutions with corresponding osmotic pressures, was about as effective as NaCl. Binet and Nicolle, on the other hand, reported that the toxicity of their tap-water solutions was greatest when the NaCl content was about 1,000 p.p.m., and decreased at lower and higher NaCl concentrations.

Additional references: (26) (61) (67) (68) (91) (99) (103) (116) (130) (141).

Nickel

Jones' data (64) show that 1 p.p.m. of nickel can be toxic to fish in soft water. Thomas (142) reported that 3.7 p.p.m. of nickel (8.1 p.p.m. $NiCl_2$) proved rapidly fatal for mummichogs in fresh tap water, but earlier he stated that 16 p.p.m. of nickel chloride killed these fish only in 5 days (141). The chloride was reported to be virtually non-toxic to the same fish in sea water, in which they tolerated 100 p.p.m. as Ni for more than 2 weeks, absorbing measurable amounts of the metal (142). However, Ellis (42) noted no pronounced influence of water hardness upon the acute toxicity of nickelous chloride to goldfish. They were killed in 12 to 18 hr. (at pH 7.4) in hard water, and in 6 to 18.5 hr. (at pH 6.3) in very soft water, by 1,000 p.p.m. of the salt. In the soft water, 100 p.p.m. and 10 p.p.m. of nickelous chloride proved fatal in about 20 to 50 hr. and in 200 to 210 hr., respec-

tively. Parallel tests with hard water were not reported. Oshima (99), testing nickel sulfate, found that 5.9 p.p.m. as Ni killed eels in 31 hr. (average). A rainbow trout was not affected in 51 hr. by 1 p.p.m. as Ni (39). Erichsen and Kaemmerer (46) found fish living in water polluted with mine effluent and said to contain 13 to 18 p.p.m. of nickel, which was believed to be present as a bicarbonate. Experimental evidence of the ability of fish to withstand these and higher concentrations of nickel was mentioned, but was not presented. The same authors (70) reported that 50 p.p.m. Ni, in a tap-water solution of nickel sulfate, killed sticklebacks in 49 to 60 hr.

Additional references: (11) (62) (91) (116).

Potassium

The data of Jones (64) and Garrey (50) show that potassium salts (nitrate and chloride) can be toxic to fish in soft tap water and distilled water at concentrations between 50 and 200 p.p.m. as K. It is noteworthy that, although Jones' sticklebacks were killed in less than 7 days by 70 p.p.m. K in a KNO_3 solution prepared with tap water, they tolerated 500 p.p.m. K for about 1 day (average). The survival time of Garrey's minnows, on the other hand, averaged about 1 day in a distilled-water solution of KCl with a potassium concentration of only 200 p.p.m. Much lower concentrations (perhaps well below 50 p.p.m.) probably would have proved fatal after more prolonged exposure. Threshold concentrations of KCl (also KNO_3 and K_2SO_4, when tested) in tap water and moderately hard lake water near 400 p.p.m. as K have been reported by Hirsch (58) and Edmister and Gray (40). Other investigators (2) (3) (61) (99) (108) have demonstrated the toxicity of higher concentrations, which proved fatal to fish in various waters within 2 days or much sooner. Oshima (99) reported that young eels tolerated about 3,900 p.p.m. K (0.1 N KCl solution) for more than 2 days, but in 0.05 N KNO_3 and K_2SO_4 solutions (1,950 p.p.m. as K) the survival time averaged only 15.7 and 27.4 hr., respectively.

Additional references: (16) (17) (29) (77) (91) (116) (148) (154) (155).

Silver

Jones' data (64) show that silver nitrate can be toxic to fish in soft water at concentrations in the neighborhood of 0.004 p.p.m. as Ag. Marsh and Robinson (90) reported that 0.04 p.p.m. $AgNO_3$ (0.025 p.p.m. Ag) killed some, but not all, chinook salmon fry in tap water within 48 hr.; 0.044 p.p.m. $AgNO_3$ proved decidedly toxic; and 0.033 p.p.m. did not prove fatal in 48 hr. These data agree well with those of Jones, obtained with mature sticklebacks (see Table I). Colloidal silver suspensions also have been reported to be highly injurious to fish (8).

Additional references: (91) (99) (103).

Sodium

The data of Garrey (50), Powers (110), and Jones (64) indicate that sodium chloride and nitrate can be toxic to fish in distilled and very soft waters at concentrations between 500 and 1,000 p.p.m. as Na. Krüger (78) reported that his sticklebacks died a little sooner in 0.05 N NaCl solutions (1,150 p.p.m. as Na) than in solutions which were 2 to 4 times as concentrated (0.1 to 0.2 N). The median survival time averaged about 8 to 9 days in these solutions, but decreased sharply at higher NaCl concentrations. Controls remained alive for 2 weeks. Gueylard's data (55) (56) indicate much greater resistance of the same species. Concentrations of NaCl up to 12,000 p.p.m. (4,720 p.p.m. Na) in distilled water and 20,000 p.p.m. (7,870 p.p.m. Na) in tap water were found to be harmless. Strictly fresh-water fish were less tolerant. The survival time of 3 species of the minnow family and of perch (which were somewhat more resistant)

averaged 4 to 8 days at NaCl concentrations of 8,500 or 10,000 p.p.m. (3,340 to 3,930 p.p.m. as Na) in distilled and tap waters (56). Tests of lower concentrations were not reported. In view of the apparent toxicity of nitrate ions, the toxicity of $NaNO_3$ to Jones' sticklebacks in the very soft water used by him (64) may not be attributable chiefly to the toxicity of sodium ions.

In harder, alkaline waters, NaCl has been reported to be toxic to some freshwater fish at concentrations between 1,500 and 2,000 p.p.m. as Na (40) (151), and $NaNO_3$ at much lower concentrations (127). However, Ellis (42) found that 5,000 p.p.m. NaCl (1,970 p.p.m. Na) in Mississippi River water had no effect on goldfish in 25 days; and Ramult (114) (115) found that salmon eggs and larvae, and also young sticklebacks, did well in 0.1 N NaCl solutions (about 2,300 p.p.m. Na) prepared with tap water. Doubling these concentrations resulted in mortality of the experimental animals, but even higher tolerable concentration limits have been reported for eels (58) and whitefish fry (40). Trout eggs resumed development after 24-hr. exposure to 21,000 p.p.m. NaCl (32). Sodium sulfate also is not very toxic to fish and fish eggs (132) (133).

Delicate marine fish and fish which occur in both fresh and salt water obviously can withstand very high sodium concentrations in physiologically balanced salt solutions such as sea water. This fact suggests negligible specific toxicity of sodium ions in the balanced solutions. The salinity tolerance of fish evidently depends chiefly upon the efficiency of their mechanisms for osmotic regulation in salt water (15). It may be markedly influenced by acclimatization, and can vary greatly with the age of the fish. Recently-hatched rainbow trout could not withstand a salinity of 5,000 p.p.m. as NaCl, whereas older trout withstood salinities 5 to 6 times as great (20).

Additional references: (2) (3) (16) (17) (26) (34) (41) (54) (60) (61) (65) (72) (77) (82) (83) (91) (94) (95) (99) (102) (106) (107) (108) (111) (116) (117) (118) (119) (145) (148) (154) (155).

Strontium

Jones' data (64) show that a concentration of strontium nitrate equivalent to about 1,500 p.p.m. of strontium can be decidedly harmful to fish in soft water. Powers (108) and Iwao (61) demonstrated the lethality of much higher concentrations of this salt and of strontium chloride, through experiments of relatively short duration. Powers' data (108) indicate that the nitrate is somewhat more toxic than the chloride in solutions of equal molarity. Yet, goldfish were found to be still alive after exposure for 4 days to a concentration of the nitrate equivalent to 3,200 p.p.m. Sr. There is no wide disagreement between this result and those of Jones, who experimented with sticklebacks (see Table I).

Additional references: (91) (116).

Tin

Oshima (99) reported that a concentration of stannous chloride equivalent to 1.2 p.p.m. of tin was the highest concentration tolerated by young eels for 50 hr., and that 6 p.p.m. as Sn (the next higher concentration tested) proved fatal in 2.8 hr. (average). The nature of the water used and the pH values of the experimental solutions are not known. Ellis (42) reported that 1,000 p.p.m. of stannous chloride, added to very soft water (pH 6.4) and to hard water (pH 7.8), killed goldfish in 1 to 1.5 hr. and in 4 to 5 hr., respectively. The pH values of the solutions were 3.5 and 3.8, and water acidified to pH 3.5 and 4.0 with hydrochloric acid had been shown to be about as rapidly lethal as these solutions. Inasmuch as more dilute solutions of stannous chloride, with tolerable pH values, evidently were not tested, the experiments reported prove nothing. Finkel and Allee (47) noted that concentrations of stannous chloride up to 0.6

p.p.m. as Sn in a synthetic "pond water" with a rather unusual mineral content did not harm goldfish during 20-day tests. The solutions were renewed periodically. Higher concentrations apparently were not tested. There is evident need for further investigation of the toxicity of tin salts, which is complicated by the acidity and instability of solutions and by precipitation occurring when these are diluted even with distilled water.

Zinc

The data of Jones (63) and Oshima (99) show that concentrations of zinc sulfate and chloride between 0.3 and 0.7 p.p.m. as Zn can be decidedly toxic to fish. Oshima's eels were killed in 12 hr. (average) by 0.65 p.p.m. of the chloride as Zn. Rushton (126) reported that young carp were killed within a day by 1 p.p.m. of zinc chloride (about 0.5 p.p.m. Zn) in tap water, although much earlier (123) he had claimed that 1,000 p.p.m. of zinc sulfate had no effect on trout in 1 day. Pronounced toxicity to various fish of zinc salt concentrations between 5 and 15 p.p.m. as Zn has been reported by several investigators (1) (39) (51) (92).

Ellis (42) reported that 100 p.p.m. of zinc sulfate in hard water had no apparent effect on goldfish within 4 days, whereas 1,000 p.p.m. proved rapidly fatal. The solutions (pH 7.6 to 7.2) were renewed continually by means of constant-flow apparatus. Ellis also stated that 100 p.p.m. of zinc sulfate killed many goldfish in 5 days. Thomas (141) reported 200 p.p.m. of zinc sulfate to be apparently non-toxic to mummichogs in sea water, whereas 10 p.p.m. of the salt killed these fish within 2 days in fresh water.

The danger of contamination with zinc from galvanized iron piping, etc., of water in which fish are held has been discussed repeatedly (4) (5) (19) (48) (51) (74) (89) (103) (105). Affleck (5) claimed that 0.01 p.p.m. of zinc in a contaminated soft hatchery water caused 54 per cent mortality among 628 young rainbow trout (alevins) in 28 days (at 8° to 12° C.); 0.04 p.p.m. prevented hatching of all of 328 rainbow trout eggs (at 4° to 9°C.); and 0.13 p.p.m. killed all of 18 rainbow trout fingerlings in 24 hr., but none of 18 brown trout fingerlings in 20 days (at 9° to 12° C.) Methods of chemical analysis of the water and sampling procedures were not reported. Affleck's conclusion that "in acid waters with a very low mineral content 0.01 p.p.m. Zn is toxic to ova and alevins of brown and rainbow trout," is not adequately supported by the data presented, but it appears that very low concentrations of zinc probably were responsible for the observed mortality. It was reported that heavy mortality of trout fingerlings which had been exposed for short periods (15 min. and 4 hr.) to contaminated water in galvanized iron cans occurred within 48 hr., although the fish were apparently normal at the time of their transfer to uncontaminated water. Burghduff (19) reported similar observations.

Kleerekoper (74) attributed contamination of a soft hatchery water containing much free CO_2, and resulting rapid mortality of fish, to the formation of soluble zinc bicarbonate (5 to 10 p.p.m. as Zn) in galvanized pipes. Finn (48) reported mortality of brook trout in contaminated aquarium water with a zinc content of 1 p.p.m. Goodman (51) stated, however, that brook, brown, and lake trout apparently were able to withstand about 8 to 11 p.p.m. of zinc, found later in the water of the same aquarium (San Francisco's Steinhart Aquarium). He suggested that gradual conditioning may have resulted in increased resistance. Rainbow trout appeared to be less tolerant. Experiments with young rainbow trout, hatched successfully in water containing about 1 p.p.m. of zinc, to which $ZnSO_4$ and small amounts of H_2SO_4 (for preventing the formation of a precipitate) then were added, showed that their resistance increased with their age. Only 2 of 20 trout 10 to 14

days old tolerated 4 p.p.m. of zinc for 48 hr., and only 55 per cent tolerated 3 p.p.m. All trout 10 weeks old withstood 4 p.p.m. of zinc for 48 hr., but only 10 per cent withstood 6 p.p.m.

Jones (66) found no fish in a soft, acidic, mine-polluted river water containing 0.7 to 1.2 p.p.m. of zinc in solution, and also a trace to 0.05 p.p.m. of lead, when the river was at normal level.

Additional references: (11) (26) (35) (53) (62) (68) (84) (130) (134).

Summary and Conclusions

1. All metal cations apparently can be toxic to fish in rather dilute (less than 0.05 M) physiologically unbalanced solutions of single metal salts. In solutions prepared with natural waters containing certain dissolved minerals, and in other mixed salt solutions, the metals often are much less toxic than they are in the simple solutions, because of the antagonistic action of different metal cations. Calcium, in concentrations which occur often in natural fresh waters, markedly counteracts the toxicity of Na, Mg, and K ions, and of at least some of the very toxic heavy metals, such as lead, zinc, and copper.

2. On the other hand, some of the highly toxic metals, such as zinc and copper, are strongly synergistic. When almost equally toxic solutions of salts of these metals (for example, $ZnSO_4$ and $CuSO_4$) are combined, the resulting mixture can be much more rapidly fatal to fish than were the component solutions.

3. Simple solutions of many metal salts are decidedly acidic, because of hydrolysis. Precipitation of nearly insoluble compounds of the metals (hydroxides, basic salts, etc.) occurs often when these salts, and some others, are added to natural waters. The concentration of active metal in solution thus may be greatly reduced, depending often on pH and the concentration of liberated CO_2, which is driven off when the solutions are aerated. The toxicity of the solutions varies correspondingly.

4. The harmful action of some metal salts is believed to be internal or intracellular, but that of salts of highly toxic heavy metals may be chiefly external. Precipitation or coagulation of mucus on the surface of the gills, in the presence of these metals, is believed to interfere with the respiratory function of the gills. The lethality of balanced salt solutions may be referable chiefly to their high osmotic pressure, rather than the specific toxicity of any particular ions. Anions associated with metal cations in solutions of metal salts undoubtedly can influence the toxicity of the solutions in various ways. Pronounced differences of the lethality of comparable (equimolar) solutions of such salts as the chloride, sulfate, and nitrate of a highly toxic metal (Cu, Zn, etc.) have been reported. There is no convincing evidence, however, that the influence of relatively harmless anions resulting from dissociation of these salts when they are added to natural waters is often practically important.

5. The lethality of some metal salt solutions to fish is markedly influenced by the temperature, the dissolved oxygen concentration, and the volume of experimental solutions in which the fish are held. The purity of chemicals tested and the duration of the tests are other important considerations when toxicity data are evaluated or applied. Results of toxicity tests of very brief duration, such as 6 hr. or less, can be very misleading. Acclimatization of fish to highly toxic metal salts may occur, but apparently has not been demonstrated conclusively, as has been acclimatization to some balanced salt mixtures (saline waters).

6. Metal-containing industrial effluents usually are complex mixtures, and they are discharged into waters of varying mineral content and pH. Limits of harmless concentration of the individual metals, which sometimes have been prescribed, obviously can-

not be uniformly applicable to all receiving waters. Simple lists of such critical concentrations, which have been published for the guidance of waste disposal engineers, are unreliable and often misleading. Generally, metal salts are likely to be less harmful to fish in hard, alkaline waters than in waters of low mineral content. However, the available data on the toxicity of individual salts even in very soft, acidic water do not necessarily show how much dilution of a mixed solution of these salts, or complex waste, would be always adequate. The toxicity of each waste, diluted with a particular receiving water, should be evaluated experimentally by appropriate bio-assay methods (36).

7. Sodium, calcium, strontium, and magnesium ions are certainly among the least harmful to fish of the metallic cations. They can be classed together with the moderately toxic potassium, lithium, barium, manganous, and cobaltous ions as metal cations of relatively low toxicity for fish. With the exception of cobalt (of which 7 to 15 p.p.m. sometimes proved toxic) and manganese (in one instance only), these metals have not been reported to be fatal in water of any kind at concentrations below 50 p.p.m. All except cobalt and lithium are said to have been tolerated by some fish for 24 and 48 hr. in concentrations near 3,000 and 2,000 p.p.m., respectively, in some waters in which presumably no considerable precipitation of insoluble compounds of the metals occurred.

8. Silver, mercury, copper, lead, cadmium, aluminum, zinc, nickel, and trivalent chromium, and perhaps also tin and iron, as well as some less important rare metals, such as gold, cerium, platinum, thorium, and palladium, can be classed as metals of high toxicity for fish. This classification is deemed valid even though salts of some of these metals are comparatively harmless in highly mineralized waters, because of precipitation of insoluble compounds and antagonism.

9. Cupric, mercuric, and silver salts are extremely toxic. Solutions containing 0.02 to 0.004 p.p.m. of the metals proved harmful to fresh-water fishes under some conditions. Zinc, cadmium, lead, and aluminum apparently are not quite as toxic. All of these metals have proved definitely injurious, however, at concentrations between 0.1 and 0.5 p.p.m. when their salts were added to soft water. Moreover, as little as 0.01 p.p.m. of zinc, detected in very soft water contaminated through contact with galvanized iron, has been reported to be fatal for young trout; and questionable evidence that very much lower concentrations of cadmium (below 0.001 p.p.m.) can be fatal for goldfish has been published.

10. Nickel and chromium have not been reported to be demonstrably toxic in any water at concentrations much less than 1 p.p.m.; and some of the comparable data reported in the literature reveal no pronounced difference between the toxicity of nickel and that of cobalt and manganese. Classification of nickel and chromium, together with some of the less toxic metals, such as cobalt, as metals of intermediate toxicity may prove justifiable, therefore, in the light of additional information. Tin (its lowest reported lethal concentration being above 1 p.p.m.) and iron, the relative toxicity of which is very difficult to judge on the basis of available data, may belong to the same (intermediate) category.

11. Hexavalent chromium, in solutions of chromates or dichromates, evidently is not as toxic to fish as trivalent chromium can be in simple solutions of chromic salts. Concentrations much below 20 p.p.m. as Cr (hexavalent) have not been shown to be toxic in any water (including distilled water), whereas less than 2 p.p.m. of trivalent chromium in soft water proved rapidly fatal. Solutions of permanganates are much more toxic than manganous salt solutions with equivalent manganese content.

12. Iron in some waters has been reported to be harmful to fish at concentrations as low as 0.1 to 1.0 p.p.m. However, sufficient evidence of toxicity of such small amounts of iron in solutions of the common ferric and ferrous salts with tolerable pH values has not been found. Some investigators reported much higher concentrations to be apparently harmless in various waters, or were unable to demonstrate toxicity of solutions which were not rendered excessively acidic through hydrolysis of the salts. The lethality of certain waters contaminated with iron salts has been ascribed by different authors to the harmful action of hydrogen ions, ferrous or ferric ions, precipitated iron hydroxide, and basic iron salts. Much additional investigation of factors which influence the toxicity of iron salts to fish evidently is needed. The same can be said of the salts of other important metals, some of which have received much less attention than has iron.

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Stream Pollution

TOXICITY OF SOME ORGANIC INSECTICIDES TO FISH

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The use in agriculture of certain new organic insecticides that are extremely toxic to fish presents problems, of which all who are concerned with water pollution should be aware. Application of some of these insecticides to crops apparently has resulted in serious pollution of streams and reservoirs into which these materials have been washed from the soil by heavy rains. It has been reported that quantities greatly exceeding the recommended dosages often have been applied. Increased awareness of the hazards involved should result in more judicious use of these toxicants for the control of pests. It may also help to explain correctly some instances of fish mortality in areas where insecticides have been applied, which otherwise might be erroneously ascribed to industrial or municipal pollution.

The possibility of dangerous contamination of domestic water supplies with the toxicants in question, which may be harmful to human consumers, also deserves attention. Because the presence of these substances in low concentrations in water may not be readily detected otherwise, the use for this purpose of some convenient and available aquatic animals as bio-reagents has received some consideration. Information about concentrations which can be detected by such monitorial tests is essential.

Representative experimental data on the toxicity of various new organic insecticides to fish in aquaria, and also in small ponds, have been presented by Lawrence (4) and Surber (7)(8). The latter author has also summarized the results of other investigators. Tarzwell (9)(10)(11) has reported other pertinent observations made in the field. The results of some additional laboratory experiments on the toxicity of aldrin, toxaphene, and a BHC–DDT mixture to fish are reported here. This investigation was undertaken in 1950 at the request of the Division of Water Pollution Control, U. S. Public Health Service, after extensive fish mortality, attributed to the contamination of waters with insecticides used for the control of cotton insects, occurred in at least 15 streams of the Tennessee River drainage basin in Alabama (12)(13). Fish mortality following the dusting of cotton fields in Alabama with toxaphene dust had been observed earlier (1)(4). The use of goldfish as experimental material in the tests reported here was requested, inasmuch as these fish reportedly were being used at some water treatment plants as biological reagents for detecting contamination of municipal water supplies with the toxicants studied. The use of experimental water with a total alkalinity in the neighborhood of 75 p.p.m. as $CaCO_3$ also was suggested.

Experimental Procedures

The hardy goldfish usually is not the most desirable test animal for use in

toxicity bio-assays of industrial wastes and other water pollutants (2). Nevertheless, in accordance with the previously mentioned request, goldfish (uncolored or "wild" variety, with a few exceptions) 2 to 3 in. long and averaging about 2.7 g. in weight were used in most of the experiments. Very young fathead minnows (*Pimephales promelas*) 1¼ to 1¾ in. long and averaging about 0.4 g. in weight also were used in some tests. The experimental water, prepared by diluting a very hard spring water with distilled water and aerating the mixture thoroughly, had a total alkalinity of 75 p.p.m. as $CaCO_3$. The tests were performed at a constant temperature of 20° C. (68° F.), to which the test animals had been previously acclimatized. The experimental aquaria were cylindrical glass jars 12 in. in diameter, containing usually 15 l. of the liquid tested and only 2 or 3 goldfish. The large volume of liquid used (at least 5 l. per goldfish) was deemed desirable because it has been shown that the lethality of an organic insecticide, such as DDT and rotenone, to fish in small aquaria may depend on the amount of toxicant available, as well as the initial concentration (5). Ten of the very small minnows were held in each test jar with 15 l. of liquid. The material to be tested was shaken in a flask with a small amount of water, and measured quantities of the resulting suspension or emulsion then were mixed with the diluent water in the aquaria, before the introduction of the fish. The experimental media usually were not renewed, and they were not aerated artificially during any of the tests. The dissolved oxygen supply was ample throughout all tests. No mortality occurred among goldfish and minnows used as controls.

Because the number of available healthy goldfish was limited, and for other reasons, accurate determination of median tolerance limits (TL_m) for certain recommended exposure periods (2) usually was not attempted. Only 5 or 6 goldfish could be exposed to some of the critical concentrations of the substances tested, although more specimens were often used. Therefore, the experiments are deemed preliminary, and only those results are reported here which are believed to be most instructive or useful, with reference to their intended practical application. The data presented indicate only those concentrations likely to prove fatal within 10 days, and concentrations likely to cause very pronounced distress and persistent loss of equilibrium (turning over) within 24 hr. The tests usually were terminated after 10 days. The 24-hr. period is believed to be the longest observation period which may be compatible with reasonably prompt detection of contamination of water supplies by any routine, monitorial testing with goldfish. In such tests, loss of equilibrium is believed to be a more satisfactory end point than is death or complete immobilization. It occurred often several days before the death of the affected fish, thus clearly indicating toxicity of experimental solutions long before the fish died.

Some tests of the toxicity of soil samples from treated cotton fields in Morgan and Limestone Counties, Alabama, collected late in September 1950, also were performed. Dusting of the cotton fields had been discontinued in August. The samples were tested in November and December, in order to determine whether or not water can be rendered toxic through contact or contamination with such soil. Four goldfish were held in 10 l. of water to which 1 kg. of soil had been added. These suspensions were artificially aerated and gently agitated during the tests by means of compressed air, released from a disperser suspended in each jar.

Results (Synopsis)

Aldrin

Chemically aldrin is hexachloro-hexahydro-dimethano-naphthalene. Both suspensions of a dust with a 2.5 per

cent "aldrin equivalent" rating (2.37 per cent aldrin, 1.79 per cent related compounds, 95.84 per cent inert ingredients) and emulsions made with an aldrin and hydrocarbon preparation having an aldrin equivalent rating of 23 per cent (22.8 per cent aldrin, 17.25 per cent related compounds, 49.95 per cent petroleum hydrocarbons, 10 per cent inert ingredients) were tested. After prolonged exposure (10 days), there was virtually no difference between the percentages of goldfish surviving in emulsions and dust suspensions of equal strengths, expressed as aldrin equivalents.

It is noteworthy that some studies reported in the literature have shown DDT to be more harmful to fish in emulsions than when it is applied in the form of dusts to the water surface (3)(7)(11). The concentration of the aldrin preparations, expressed as the aldrin equivalent, which is fatal in 10 days to 50 per cent of goldfish (10-day TL_m) under the conditions of the experiments was estimated to be approximately 0.02 p.p.m., the observed overall survival having been 20 per cent at 0.032 p.p.m. and 90 per cent at 0.01 p.p.m. Renewal of the experimental media after 24, 48, and 96 hr. during some of the tests had no apparent influence on the final results. The survival time of goldfish killed within 10 days averaged somewhat less in emulsions than in corresponding dust suspensions, but the difference was not very pronounced. The concentrations of both of these preparations at which half the goldfish are markedly affected (turn over) within 24 hr., where estimated to be in the neighborhood of 0.05 p.p.m., as aldrin equivalents. However, after 24 hr. some fish were strongly affected by 0.032 p.p.m., whereas a few were not markedly affected by 0.1 p.p.m.

Results obtained with young fathead minnows did not differ greatly from those obtained with goldfish. About half the minnows were killed within 10 days in both an emulsion and a dust suspension at a concentration of 0.018 p.p.m., expressed as the aldrin equivalent; 0.01 p.p.m. proved fatal to some.

Toxaphene

In the experiments reported here, only a dust containing 20 per cent toxaphene (chlorinated camphene) and 80 per cent inert ingredients was used. Goldfish survived for 10 days at a concentration of 0.0032 p.p.m. as toxaphene, but 7 of 9 were killed within 10 days by 0.0056 p.p.m., and all were killed by 0.01 p.p.m., as toxaphene. A 10-day median tolerance limit somewhat below 0.005 p.p.m. of the active ingredient is indicated. The toxaphene concentration at which only 50 per cent of goldfish are markedly affected and show persistent loss of equilibrium after a 24-hr. exposure was estimated to be about 0.025 p.p.m.

BHC–DDT Mixture

A dust, containing 3 per cent of the gamma isomer of benzene hexachloride, 5 per cent other BHC isomers, 5 per cent DDT, 40 per cent sulfur, and 47 per cent inert ingredients, was tested using goldfish only. The concentration of this dust tolerated for 10 days by only 50 per cent of the fish (10-day TL_m) was found to be near 3 p.p.m. The concentration at which one-half the fish turn over within 24 hr. was judged to be in the neighborhood of 25 p.p.m. It should be noted that a suspension containing 3 p.p.m. of this dust contains 0.24 p.p.m. BHC (but only 0.09 p.p.m. gamma isomer BHC) and 0.15 p.p.m. DDT.

Soil Samples

Two of the soil samples taken from treated cotton fields did not prove markedly toxic. Only 1 of 16 goldfish used in the tests (8 for each sample) died within 10 days. The sample which killed no fish was taken from a field said to have been treated with about 84 lb. of toxaphene dust per acre (7 dustings). Another sample, from a

field reported to have been treated with about 108 lb. of toxaphene dust per acre (10 dustings), killed 2 of 4 goldfish within a week. Still another sample, from a field said to have been treated with only 30 to 31 lb. of toxaphene dust per acre (3 dustings), proved most toxic, killing 7 of 8 goldfish within a week. An aqueous extract of the same soil, prepared by filtering the suspension, proved at least as toxic as the unfiltered mixture of water and soil. All of 4 goldfish died in the filtrate within 6 days. This filtrate was moderately turbid (milky), because of colloidal material that passed through the coarse filter paper used.

Discussion

Aldrin appears to be less toxic to goldfish than toxaphene, but much more toxic than DDT and BHC (including the gamma isomer), under the conditions of the tests reported here. However, because the toxicity of some of these insecticides is known to vary markedly, depending on the nature of the preparations, no definite conclusions concerning the relative toxicity of pure active ingredients of the mixtures tested, or of other comparable preparations, can be based on the test results. The relatively low toxicity of the BHC–DDT dust, which has a higher percentage of active ingredients than the more toxic aldrin dust, is interesting, in view of the high toxicity to fish of both DDT and BHC (especially the gamma isomer) in some forms or preparations (3)(8). All the lethal concentration limits reported here agree quite well, however, with some of the other comparable data based on experiments with various fish species and reported in the literature cited heretofore.

The great toxicity of toxaphene to fish in their natural habitat is revealed by the results of field studies at Savannah, Ga., where an oil solution was sprayed on the surface of ponds at weekly intervals (11). In one pond, with an average depth of 9 ft., the first application at the rate of 0.2 lb. of toxaphene per acre, or about 0.008 p.p.m., apparently killed no fish; but two applications (totalling 0.016 p.p.m. toxaphene) killed all the fish. In another pond, averaging 3 to 4 ft. deep, the first application at the rate of 0.1 lb. per acre, or about 0.01 p.p.m., killed most of the fish present, and three such treatments killed all the fish.

The relatively high percentage of active ingredient in the toxaphene dust tested, as well as the high toxicity of this ingredient, should be noted. Of the three dusts (commercial preparations) tested, the toxaphene dust is by far the most toxic to goldfish. Concentrations of these dusts judged to be near those which are most likely to cause death in 10 days and loss of equilibrium after 24 hr. (50 per cent effective concentrations) under experimental conditions described herein, are as follows:

	Die in 10 days	Turn over in 24 hr.
Toxaphene dust (20% toxaphene)	0.025 p.p.m.	0.125 p.p.m.
Aldrin dust (2.5% aldrin equiv.)	0.8 p.p.m.	2 p.p.m.
BHC–DDT dust (5% DDT and 8% BHC, including 3% gamma isomer)	3 p.p.m.	25 p.p.m.

Equal rates of application (dosages) of toxaphene and BHC–DDT dusts like those tested having been recommended for the control of cotton insects (6), the use of toxaphene dust evidently should be avoided where possible damage to fish life is an important consideration. Under these circumstances, use of the BHC–DDT dust tested apparently is preferable to the use of an equal amount of aldrin dust.

The tests of soils from toxaphene-treated fields show that stream waters can be rendered toxic to fish by drainage from such fields. The lack of correlation between the quantity of toxicant applied and the observed toxicity of the soil samples may be due to un-

even distribution of the toxicant after repeated washing of the soil with rain water. Toxaphene washed into streams together with soil evidently is not rendered innocuous by adsorption on the soil particles, or removed effectively from the water upon sedimentation of most of the settleable solids. The toxicants tested may be more effective, however, in the experimental aquarium water than in some natural, more or less turbid waters, and the concentrations of these insecticides which can be detected through bio-assays with fish may vary accordingly.

Acknowledgment

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A STANDARDIZED METHOD FOR DETERMINING TOXICITY OF PURE COMPOUNDS TO FISH

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The objective of this paper is to present a readily reproducible method, as employed at Louisiana State University, for determining the toxicity tolerance limits of fish to pure compounds.

Much of the experimental work on bio-assay reported in the literature is admittedly of great value in many respects, but is not, in general, directly comparable, due to the fact that there are great variations in procedures and methods of interpretation of these experiments. There is also a noticeable failure on the part of most experimenters to report fully the details of the conditions under which the tests were conducted.

The major fault of the reported experimental work in bio-assay of pure compounds has been the lack of a uniform solution to serve as the dilution and acclimatization medium for the tests. In most cases the experimenters employed water from nearby streams or lakes, thus preventing the repetition of the experiments by workers in other localities.

In addition to this lack of a standard diluent, various other shortcomings are noted. Among these are the number of fish to be employed in each test concentration, the length of each test, the volume of solution per test, the temperature limits, and others.

Recently, Doudoroff *et al.* (3) published a very comprehensive procedure for conducting bio-assay tests on industrial wastes. This procedure was derived from an earlier publication by Hart, Doudoroff, and Greenbank (7). Although the work reported here was completed prior to the publication of the method by Doudoroff, the method adopted by the Louisiana laboratory closely parallels the recommendation made by Doudoroff, the only major differences being the length of time employed for the tests (24 hr. as opposed to the 48-hr. test period recommended by Doudoroff) and the substitution of a synthetic diluent for stream or lake water.

The use of this synthetic diluent is justified, inasmuch as the object was to derive a practical method, reproducible in any laboratory, for bio-assaying pure compounds without regard to a specific pollutional problem. The value of the 48-hr. testing period, as opposed to the 24-hr. period, to the author's knowledge has not been demonstrated.

The Standardized Diluent

Perhaps the most important single factor which makes possible the successful duplication of results by this method was the water used as the diluent and acclimatization solution. This water has been designated as "standard reference water," and comprises a water containing all the major ions in concentrations and proportions typical of a mean surface water of the United States. It is patterned after the "United States mean dilution water" of Hart, Doudoroff, and Greenbank (7).

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The standard reference water is prepared as follows: *

Water that has been previously distilled in a Barnstead still is used in the preparation of the stock solutions and subsequent dilutions.

Stock solution 1. Dissolve 71.0 g. $MgSO_4 \cdot 7H_2O$, 6.5 g. K_2SO_4, and 0.2 g. $MnSO_4 \cdot 4H_2O$ in distilled water and dilute to 1 l. with distilled water.

Stock solution 2. Dissolve 18.6 g. $CaCl_2 \cdot 2H_2O$ in distilled water and dilute to 1 l. with distilled water.

Stock solution 3. Dissolve 25.0 g. $NaHCO_3$, 3.0 g. NH_4NO_3, and 1.1 g. $K_2HPO_4 \cdot 3H_2O$ in distilled water and dilute to 1 l. with distilled water.

Stock solution 4. Dissolve 32.2 g. CaO in distilled water and dilute to 1 l. with distilled water. Pure CO_2 is blown through this mixture to make a $CaCO_3$ slurry.

Stock solution 5. Dissolve 62.6 g. $Na_2SiO_3 \cdot 9H_2O$ in distilled water and dilute to 1 l. with distilled water.

Stock solution 6. Dissolve 1.2 g. $FeCl_3 \cdot 6H_2O$ in distilled water and dilute to 1 l. with distilled water.

For each liter of standard reference water to be prepared, 1 ml. each of solutions 1, 2, and 3 is added to the desired amount of distilled water. Pure carbon dioxide gas is dispersed into this solution, by means of a porous gas disperser, for 15 min. The pH of the solution at this point should be approximately 4.3. To this solution 1 ml. of solution 4 is added for each liter of standard reference water, and carbon dioxide is again added until the solution becomes clear. The pH of the solution at this point should be approximately 5.1. Compressed air is then bubbled through the solution for 25 min., bringing the pH to approximately 7.9. For each liter of water, 1 ml. each of solutions 5 and 6 is then added and the solution is aerated for 60 min., the final pH of 7.9 remaining constant within 0.1 pH units after aeration.

This dilution water has been used successfully for experimental work with both invertebrates (2)(5)(6) and fish (1)(4)(8), and it is felt that the standard reference water should prove satisfactory for most bio-assay tests employing fish as the test animal.

* Based on a formula of the Waste Control Laboratory, Atlantic Refining Co., Philadelphia, Pa.

The Test Animal

It is desirable that the fish chosen as test animals be representative of the aquatic fauna of the region in which the results are to be applied, but in those cases where the studies are of an empirical nature the fish selected may be chosen to fit the point in question.

For purposes of study in this laboratory, the bluegill (*Lepomis macrochirus* Raf.) is employed, since it has been shown to be intermediate in sensitivity to toxic compounds (7). The test fish are obtained from the United States Fish Culture Station at Natchitoches, La.

When the fish are brought to the laboratory they are placed in large concrete holding tanks. Upon their transfer into the laboratory proper they are placed in tap water, the temperature of which has been previously adjusted to that of the outside tanks. In this way, the temperature of the inside laboratory is attained gradually and with no ill effects.

After the fish have been acclimated to the temperature of the room, they are placed in standard reference water that has also been adjusted to room temperature and well aerated for several hours. They are held in the reference water from 4 to 7 days. Approximately one-half of this water is replaced every 4 days, as no filter mechanism is provided for the tanks.

The daily feeding of the fish is discontinued for 24 hr. prior to the be-

ginning of the tests, and any fish showing signs of being in distress are removed from the tanks during this period. If more than 10 per cent of the fish appear diseased or in weakened condition, the entire lot is discarded.

For a more complete discussion of the acclimatization and handling of fish, the reader is referred to the paper by Doudoroff *et al.* (3).

The Physical Factors

The temperature at which the experiments are conducted is kept constant by means of a constant-temperature bath in which the test jars are immersed. This bath is equipped with a flexible-type immersion heater, controlled by a mercury thermoregulator through a sensitive mercury relay, and an impeller-type circulation pump. During the earlier part of the testing program the temperature was maintained at 25° C., but after the installation of air conditioning apparatus in the laboratory it became more practical to conduct the tests at 21.5° to 22.0° C.

The tests are conducted in glass jars measuring 14 in. in height and 8 in. in diameter, with a total capacity of 8 l. A total of 6 l. of solution is used in each test. This depth and volume has proven adequate to accommodate 10 fish measuring 8 cm. or less in length.

The Test

After the fish have been properly acclimated to the temperature and to the reference water under the conditions of the tests, the test solution, at the desired concentration, is prepared and adjusted to temperature in the constant-temperature bath. This latter step is completed at least 1 hr. before the test is to begin. At this point the solution is aerated by means of compressed air through a porous stone disperser for at least 10 min., or until the dissolved oxygen level (determined by a modified Winkler method) reaches a minimum of 7 to 8 p.p.m. The air stream is then reduced to a rate just sufficient to maintain the dissolved oxygen level. (If the compound under investigation is volatile, another method of aeration must be employed to reduce the loss of the compound. Unfortunately, no satisfactory method has been reported in the literature.) Then about 200 ml. of the solution is drawn off to be used for collecting data on the physical properties of the solution and for rinsing the fish off before placing them in the test jar, in order to prevent undue dilution of the test concentration.

As soon as the 10 fish are placed in the test solution, the time is recorded and the fish are carefully observed for signs of anoxia or any other signs of extreme discomfort.

After 24 hr. the test is checked for the percentage of mortality and the general condition of the surviving fish. These results are recorded, and if no fish, or only a small percentage of the fish, are killed by the test concentration, they are allowed to remain in the test for an additional 24 hr. to estimate the 48-hr. median tolerance limit.

Determination of 24-Hr. Median Tolerance Limit

The 24-hr. median tolerance limit (written as 24-hr. TL_m) is defined as the concentration at which 50 per cent of the test animals survive for 24 hr. This concentration may be expressed as per cent or in p.p.m.

The results obtained are plotted on semi-logarithmic paper, with the concentrations on the logarithmic scale and the percentage of mortality on the arithmetic scale. The results from two or more tests in which some survival was obtained make it possible to estimate the percentage of mortality for various concentrations of the compound being tested. After several tests are completed it is possible to interpolate the 24-hr. TL_m, even though

that exact concentration is not tested (3)(7).

Summary and Conclusions

A method has been developed for determining the toxicity tolerance limits of fish to pure compounds, the method having the advantage over previous methods of being readily reproducible in any laboratory.

The reproducibility of this method is made possible by the use of a standardized water, designated as "standard reference water," for dilution and acclimatization purposes. This water is readily duplicated, as it is prepared from distilled water and given amounts of inorganic salts.

The method described has been used successfully for bio-assay work employing both invertebrate and vertebrate animals, and is currently being employed in a laboratory at Louisiana State University.

Acknowledgments

The work reported herein was conducted on a project sponsored by the Louisiana Petroleum Refiner's Waste Control Council and administered by the Department of Zoology, Physiology, and Entomology, Louisiana State University.

Also acknowledged is the aid of the Division of Research and Statistics, Louisiana Department of Wild Life and Fisheries, in the provision of laboratory facilities.

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THE OPERATOR'S CORNER

CONDUCTED BY HERBERT P. ORLAND

TRAINING OF EMERGENCY PERSONNEL

Every superintendent or operator of a wastes treatment plant has an implicit responsibility to insure continued operation of his plant in the best manner possible despite personnel matters beyond his control. But the emergency personnel that step in to fill the gap caused by illness, accident, or local or national catastrophe must have had at least some preparatory training in order to carry on with any semblance of order and even "make-do" efficiency.

The problem is not acute in large or even medium-sized plants, although it might be a considerable factor under conditions requiring functioning of civil defense components. In small plants, however, it is always present—whether the threat be one of atomic attack, local catastrophe, or only illness or death of the single operator.

Where do the temporary replacements come from? How are they trained? In the case of at least one institutional plant that has come to our attention, power plant employees have been given basic instruction and have had some practical operating experience at the sewage treatment plant under the regular operator. The program has been carried out on the employer's time. In this way an emergency crew has been built up to fill in when needed.

In the case of the one-man municipal plant, the same procedure might be followed with a few employees from other municipal departments, particularly where their work would otherwise be seasonal or spasmodic. During slack periods in their normal work their services could well be used at the sewage treatment plant, at the same time giving them basic training as emergency operators. The same principle could be applied by treatment plants servicing small industrial installations. At least some specialized wastes plant operational training of a few industrial maintenance or operating personnel would seem to be good insurance against a production shutdown because of interrupted operation of the wastes treatment facilities.

Untold damage can be caused to both plant equipment and treatment processes by an emergency "pinchhitter," no matter how well-meaning, if he is not previously prepared to handle the situation. It is obvious, therefore, that the time to start his training is not when the emergency strikes, but now, while there is still time to complete whatever program is decided on, before it is needed.

Inauguration of a planned campaign to provide at least "two-deep" training of emergency operating personnel certainly should be a matter of highest priority in every waste treatment administrator's planning schedule.

H. P. O.

EVOLUTION OF A SAFETY PROGRAM

By John R. Szymanski

Superintendent, Sewage Treatment Plant, New Britain, Conn.

The Sewage Disposal Commission of the city of New Britain, Conn., directs the operations of the sewage treatment plant. In the course of its duties as a municipal board the Commission meets at least once each month to review and act on any pertinent matters.

The monthly meetings are scheduled in the City Hall. However, during the course of these meetings the Commission decided that it would be advantageous to hold every third meeting at the sewage treatment plant and to have a general inspection of the plant and its facilities after each of these meetings.

Soon after the institution of the inspection meetings it was decided to combine a safety program with the general inspection. To implement the program, a safety committee was established, with the assistant superintendent of the plant as the permanent member of the committee. The two rotating members of the committee consist of the day-shift operator and the relief operator, who serve for four weeks at a time.

The committee of three receives and reviews suggestions from other members of the plant staff, and after carefully studying all recommendations, makes a written report to the plant superintendent for final disposition. Complete reports of the committee are then tabulated and presented to the Sewage Disposal Commission four times each year. The Commission, consisting of technical leaders in local industry, studies the final reports and makes any necessary recommendations.

The safety program as outlined was begun in January, 1950. Basically, it was supposed to be only a program whereby the safety of plant personnel and the visiting public was to be considered. As the program developed, however, it was found that a great many laborsaving and timesaving suggestions were produced.

It also was discovered that each of the plant employees had certain pet ideas, which had to be screened before adoption or elimination. The whole idea brought about a spirit of friendly competition and worked wonders from the morale standpoint.

The program itself has been progressive, as shown by the items outlined in Table I. The tabulated items merely indicate the extent of the reports processed through the office of the superintendent and the Sewage Disposal Commission. It will be noticed that most of the items do not involve a great deal of money, but do improve conditions from the standpoint of health, morale, and safety.

It is difficult to conclude definitely that the program has eliminated every hazard and dangerous working condition. Nevertheless, a review of the plant accident record shows that no major accident or injury has occurred since January 1, 1950.

Summarizing, safety at the New Britain sewage treatment plant has become a "must"—including safety education, safety awareness, safety reporting, and safety action.

TABLE I.—Safety Measures and Improved Operating Practices Resulting from Plant Safety Committee Action

Item No.	Condition or Suggestion	Date Reported	Disposition	Cost ($)
1	No protection afforded employees while changing valves at primary tanks	1/9/50	Guard rails installed 3/15/50	100.00
2	Sludge waste valve in basement above No. 2 sludge pump operated by standing on 6-in. line flange	1/9/50	Adequate stepladder furnished 1/15/50	10.00
3	Dewatering pump valve operated by standing on 1½-in. water line above	1/9/50	Adequate permanent stepladder furnished 1/15/50	5.00
4	Cat walk gratings between vacuum filters not secured	1/9/50	Gratings adequately secured 1/12/50	2.00
5	Grease flotation pit unprotected	1/9/50	Guard rails installed 2/13/50	18.00
6	Incinerator platform at No. 4 hearth level unprotected	1/9/50	Guard rails installed 1/20/50	25.00
7	Protruding objects at foot and head levels form hazard	1/9/50	Warning paint indications in use 1/20/50	2.00
8	Heavy and disagreeable gases accumulate in basement near sump pumps	1/9/50	Installed 24-in. exhaust fan 2/20/50	75.00
9	No outside means of support available in getting in or out of sludge concentration tanks	1/9/50	Hand grips installed above each tank 1/21/50	3.00
10	Variable-speed blower brushes exposed	1/9/50	Heavy duty safety screen installed as cover 1/22/50	3.00
11	Lime tank platform affords no protection for laborers	1/9/50	Guard rails installed 1/25/50	8.00
12	Sludge tank manholes hazardous when open	1/9/50	Wood covers provided 1/10/50	5.00
13	No water connections for immediate operational use at any of the vacuum filters	2/28/50	Water lines extended and valves installed at each filter 3/1/50	30.00
14	Medical examinations and inoculations be required	2/28/50	Inoculation program in effect, Health Department	None
15	No permanent light above sludge elevator	6/30/50	Permanent light installed 7/15/50	2.50
16	Stationary hoist for ferric chloride handling awkward and dangerous	10/1/50	Swivel hoist installed 11/2/50	7.50
17	Exposed sludge wells on final tanks are hazardous	10/1/50	Hinged aluminum covers installed 1/10/51	36.00

TABLE I.—*Continued*

Item No.	Condition or Suggestion	Date Reported	Disposition	Cost ($)
18	Floodlights directed onto final tanks do not give ample lighting for proper sampling and inspection	10/1/50	Two new floodlights installed 2/15/51	24.00
19	Inadequate protection of main floor master switches during hosing periods	2/6/51	Adequate panels installed 4/8/51	1.50
20	Inadequate footing atop sludge elevator during cleaning periods	2/6/51	Footing plate extended to furnish more security 3/10/51	2.00
21	Square corners on vacuum filters and discharge plate	7/4/51	All corners rounded 8/10/51	2.00
22	Eliminate use of gasoline as a cleaner	4/1/52	Noninflammable cleaner substituted 4/3/52	None

INTERESTING EXTRACTS FROM OPERATION REPORTS

"If we could only sell our experience for what it cost us!"—*Anon.*

Attention operators! It will be appreciated if copies of all annual reports of both large and small plants are sent to the Federation office for abstracting in this section of the Journal. Carbon copies of typewritten reports will be promptly returned on request. Please direct annual reports to: Federation of Sewage and Industrial Wastes Associations, Room 325, Illinois Bldg., Champaign, Ill.

Biennial Report of the Sewage Treatment Plant of the Orange County (Calif.) Joint Outfall Sewer for the Two-Year Period Ending June 30, 1951

By Nelson M. Launer, *General Manager*

The 19 miles of sewers comprising the system of the Orange County (Calif.) Joint Outfall Sewer are jointly owned and operated by the cities of Santa Ana, Anaheim, Orange, and Fullerton, and the sanitary districts of Placentia, Garden Grove, La Habra, and Buena Park. Administration is by an executive board consisting of one member from each of the member cities and sanitary districts. The entire system is divided into six sections, each of which is owned by the cities and sanitary districts using it.

The original primary treatment plant of the system was put into operation in 1941, since which another clarifier, three digesters, and chlorination equipment have been added. Current processing includes: (a) grit removal by mechanically-cleaned detritor unit, the grit being washed and used for fill; (b) screening by manually-raked bar screen, the screenings being buried or incinerated using sludge gas for fuel; (c) primary clarification in duplicate 90-ft. diameter, 9-ft. deep, mechanically-cleaned tanks each having a ca-

pacity of 57,000 cu. ft.; (d) separate two-stage digestion in duplicate units, one with 60-ft. diameter tanks and one with 75-ft. diameter tanks, the secondary in each case having a floating cover; (e) use of gas for sludge heating by direct steam injection, building heating, and screenings incineration; and (f) sludge drying on open beds, from which it is removed by a contractor who grinds it and delivers it to farms for fertilizer. The plant design capacity is 10.2 m.g.d. Plant effluent is discharged into the Pacific Ocean 3,000 ft. offshore in 35 ft. of water.

Personnel

The treatment plant is operated by a superintendent, a utility man, and four operators. A full-time chemist and his assistant are in charge of plant control and analyses. Beach samples for coliform determinations are taken by an employee who fills in as a maintenance man during the off-season of the year. Assistance and relief are provided by personnel of field maintenance crews and the chlorinator operators during the time of the year when chlorination is not required.

The beach chlorinator station, providing a capacity of 22,000 lb. per day, is serviced by four operators under the supervision of the treatment plant superintendent.

Sewage Characteristics

The influent handled by the Joint Outfall treatment works is very strong during most of the year, as measured

TABLE I.—Summary of 1949–50 and 1950–51 Operating Data for the Sewage Treatment Plant of the Orange County (Calif.) Joint Outfall Sewer

Item	Average 1949–50	1950–51
Equiv. population:		
B.O.D. basis	245,660[1]	345,110[2]
Susp. sol. basis	106,810[1]	145,060[2]
Sewage flow (m.g.d.)	10.478[1]	11.023[2]
Grit (cu. ft./m.g.)	2.5	2.4
Settl. sol., 2 hr. (ml./l.):		
Raw sewage	14.8	11.4
Settled effl.	1.8	1.3
Susp. sol. (p.p.m.):		
Raw sewage	334	334
Settled effl.	158	155
Reduction (%)	54.1	53.8
B.O.D., 5-day (p.p.m.):		
Raw sewage	575	565
Settled effl.	468	467
Reduction (%)	24.4	19.2
Alkalinity (p.p.m.):		
Raw sewage	347	350
Chlorides (p.p.m.):		
Raw sewage	1,040	951
Grease (p.p.m.):		
Raw sewage	48	79.5
Settled	21	32.2
Nitrogen, total (p.p.m.):		
Raw sewage	—	38
Settled	—	34
Raw sludge data:		
Gal./m.g.	2,965	2,455
pH	5.5	5.5
Tot. solids (%)	5.80	5.70
Vol. solids (%)	69.5	74.0
Tot. nitrogen (p.p.m.)	1,599	1,831
Grease (%)	0.92	1.10

[1] Fiscal year 1948–49. [2] July-Dec., 1949.

by the B.O.D. During the summer and fall months, when the canneries, citrus processing plants, etc., are in full operation, the influent reaches a B.O.D. strength of three to four times that of average domestic sewage. When measured by suspended solids, however, the strength of the sewage is not extreme. Therefore, a large proportion of the B.O.D. is due to dissolved materials, which cannot be removed by settling. This is reflected in the operating results of the plant.

Chlorination Studies

As a result of studies made during 1950–51, the use of the ortho-tolidine test for residual chlorine was discontinued as a control procedure. In its place the amperometric titration procedure, using phenylarsene oxide and back-titration with standard iodine in acid solution, was adopted. This step was taken because it was found that effective bacterial reduction could be secured with chlorine dosages below the range of ortho-tolidine measurement, but which could be controlled by amperometric titration. The net effect, based on short-term (one month) results, was a decrease in unit chlorine usage (pounds of chlorine per ton of B.O.D.) amounting to 37.46 per cent.

Operating data for the fiscal years 1949–50 and 1950–51 are summarized in Table I.

16th Annual Report of the Belvidere (Ill.) Sewage Treatment Plant for the Year 1952 *

By F. E. Peterson, *Superintendent*

Operation

Additional operational procedures, or those changed since the previous description, are as follows:

1. Both primary tank units are operated continuously, with sludge scrapers and skimmers run for one hour before the raw sludge is pumped.

2. Raw sludge is pumped to the digester at 8 AM, 4 PM, and midnight. Great care is taken to see that the sludge is as concentrated as possible, with samples being taken every 5 min. during the pumping period. The volume pumped is computed from the rise of the floating cover. Each day an amount of supernatant equal to the previous day's pumpage is removed from the digester and placed on the sludge beds. Digested sludge is drawn to the drying beds whenever the monthly tank analysis shows it to be necessary. Dried sludge is removed from the beds in a truck. Some is taken directly by agricultural or floricultural users, but most is stockpiled and later given away. No trouble is experienced in disposing of all sludge produced.

3. The activated sludge unit receives the entire flow from the primary tank. Aerators are cut in and out of service by time clock to meet the changing oxygen demand brought about by changes in either the volume or the strength of the raw sewage. From 500 to 700 p.p.m. of suspended solids are carried in the mixed liquor, with the suspended solids generally being kept lower in summer than in winter.

Maintenance

In addition to the usual maintenance procedures of oiling, greasing, painting, etc., a new hot-water tank was installed to replace the badly corroded existing one. Also, the digester was cleaned and repaired. This was necessary because of the consistently lowering digester temperatures. Work was begun on June 29. By August 20 the tank

* For last previous extract see *Sewage Works Journal*, **20**, 5, 912 (Sept., 1948).

had been dewatered and cleaned. All repairs were completed by October 16, the unit being returned to limited service on that day, and to full service on October 28. Gas production began November 20.

Operating data are summarized in Table II.

TABLE II.—Summary of 1952 Operation Data at Belvidere, Ill.

Item	Average	Item	Average
Rainfall (in.)	33.50	Sludge added (gal./m.g.)	5,861
Equivalent population (B.O.D.)	9,700	Raw sludge, dry sol. (%)	4.80
Average sewage flow:		Raw sludge, vol. sol. (%)	72.8
M.g.d.	1.039	Average pH	7.3
Gal. per capita per day	103	Average temperature (° F.)	76
Suspended solids:		Digested sludge, dry solids (%)	4.37[1]
Raw (p.p.m.)	191	Digested sludge, volatile solids (%)	64.0[1]
Settled (p.p.m.)	112	Estimated gas production (cu. ft. per capita per day)	1.61
Final (p.p.m.)	5	Operation cost ($):	
Reduction (%)	97.4	Per capita	2.06
B.O.D.:		Per m.g.	54.71
Raw (p.p.m.)	191	Pumping station operation cost ($):	
Settled (p.p.m.)	111	Per capita	0.11
Final (p.p.m.)	5	Per m.g.	2.91
Reduction (%)	97.5	Administration cost ($):	
Pounds B.O.D. per capita per day	0.165	Per capita	0.41
Aerator operation:		Per m.g.	10.73
Average detention (hr.)	9.5	Depreciation, interest, etc. cost ($):	
Mixed liquor suspended solids (p.p.m.)	553	Per capita	1.31
Return sludge (per cent flow)	20	Per m.g.	34.55
Kw.-hr. per lb. B.O.D. removed	0.633	Total cost ($):	
Sludge index	170	Per capita	3.88
Digester operation:		Per m.g.	102.90
Sludge added (g.p.d.)	6,090		

[1] Based on only two monthly samplings (Feb. and May).

18th Annual Report of the Galesburg (Ill.) Sanitary District Sewage Treatment Plant (1951 and 1952) *

By L. W. Hunt, *Superintendent*

The quantity of sewage treated, both in 1951 and 1952, exceeded that of any previous year, averaging 5.082 in 1951 and 5.343 in 1952. In 1952, 82 per cent of the interceptor flow was given treatment, with 94.0 per cent being treated during seven months of the year and 50.0 per cent during March.

A new secondary digester equipped with gas holder was placed in operation in August, 1951. Gas storage, although small (24,000 cu. ft.), makes it possible to engine-pump all the flow for a week, whereas without storage the available gas supply is about 3,000 cu. ft. per day less than is required.

The 987 tons of primary and secondary solids put into the digesters produced 8,958 cu. ft. of gas during 1952, of which 75.9 per cent was used in the gas engines to pump 94.4 per cent of the total quantity of sewage treated. A saving of $3,600 was effected during the year by using digester gas in place of electricity for power.

Plant operating data for 1951 and 1952 are summarized in Table III.

* For last previous extract see *Sewage Works Journal*, **21**, 1, 154 (Jan., 1949).

TABLE III.—Summary of Operation Data for 1951 and 1952 at the Galesburg, Ill., Sewage Treatment Plant

Item	Average 1951	1952
Connected population	32,040	34,240
Equivalent population (B.O.D.)	33,000	36,670
Rainfall (in.)	46.55	34.87
Interceptor flow (m.g.d.)	6.945	6.510
Sewage receiving primary treatment (m.g.d.)	5.082	5.343
Sewage receiving secondary treatment (m.g.d.)	5.078	5.343
Screenings (cu. ft. per m.g.)	0.56	0.39
Grit removed (cu. ft. per m.g.)	3.15	1.99
Scum removed (cu. ft. per m.g.)	0.85	1.22
pH raw sewage	7.4	7.4
pH final effluent	7.4	7.5
Suspended solids:		
Raw (p.p.m.)	153	149
Settled (p.p.m.)	78	76
Filtered (p.p.m.)	72	71
Final (p.p.m.)	37	27
Reduction (%)	76.0	82.8
Raw (lb./cap./day)	0.19	0.207
B.O.D.:		
Raw (p.p.m.)	142	149
Settled (p.p.m.)	104	108
Filtered (p.p.m.)	54	55
Final (p.p.m.)	32	29
Reduction (%)	78.3	79.4
Raw (lb./cap./day)	0.178	0.197
Filter loading:		
Pounds B.O.D./acre ft.	372	362
Pounds B.O.D./1,000 cu. ft. media	8.56	5.12
Pounds B.O.D./cu. yd. media	0.23	0.138
Primary sludge:		
Total solids (%)	7.4	7.2
Volatile solids (%)	60.3	59.9
Secondary sludge:		
Total solids (%)	1.9	1.7
Volatile solids (%)	53.3	50.3
Digested sludge:		
Total solids (%)	10.3	9.3
Volatile solids (%)	42.3	43.8
Gas production:		
Cu. ft. per lb. T.S. to digester	4.41	4.69
Cu. ft. per lb. V.S. to digester	7.23	7.80
Cu. ft. per m.g. raw sewage	4,750	4,797
Operating costs ($ per m.g.):		
Gas engines	0.87	0.05
Payroll	18.14	16.57
Power	0.97	0.75
Trucks	0.54	0.52
Laboratory supplies	0.10	0.11
New tools and equipment	—	0.06
Repairs	1.61	1.05
Office expense	0.09	0.08
Insurance	0.85	0.70
Care of grounds	0.12	0.21
Miscellaneous	0.37	0.42
Total	23.66	20.53

Annual Report of the International Airport Activated Sludge Plant, Miami, Fla., for 1951 *

By John S. Whitney, *Superintendent*

Flows at the plant are steadily increasing, due to the rapid growth of the airport and the fact that this airport has for the past few years led the nation in arrivals and departures of foreign passengers, and is steadily increasing in the number of domestic passengers handled each month.

One new terminal has been erected and is in operation. Plans also are being made to enlarge the main terminal in the near future.

In addition, a second maintenance and overhaul shop and nose hangar is under construction by one of the larger airlines. When finished this facility will be the largest of its type in the world.

Plant performance is extremely good, with only occasional troubles arising from toxic materials entering the plant.

Operating data for 1951 are summarized in Table IV.

* For last previous extract see This Journal, **23**, 8, 1046 (Aug., 1951).

TABLE IV.—Summary of 1951 Operation Data, International Airport Activated Sludge Plant, Miami, Fla.

Item	Average
Equivalent population (B.O.D.)	2,200
Rainfall (in.)	33.52
Sewage treated (m.g.d.)	0.15
Suspended solids, Gooch (p.p.m.):	
Influent	184
Primary effluent	100
Final effluent	7
B.O.D. (p.p.m.):	
Influent	296
Primary effluent	201
Final effluent	13
Reduction, over-all (%)	95
Raw sludge:	
Pumped (g.p.d.)	1,929
pH	7.0
Digested sludge, moisture (%):	
Maximum	85
Minimum	80
Chlorine:	
Used, on effluent (lb./day)	14
Residual, 15-min. contact (p.p.m.)	0.6
Power used (kw.-hr.):	
Per day	257
Per lb. B.O.D. removed	1.2
Primary tank:	
Settl. sol., influent (p.p.m.)	28[1]
Settl. sol., effluent (p.p.m.)	6.4
Removal (%)	77
pH, influent	7.6
pH, effluent	7.4
Aeration:	
Units used	2
Hours per day	43.6
Susp. sol., centrifuge (p.p.m.)	800
Settled (%)	36
Sludge vol. index	435
D.O., aerators (p.p.m.)	1.6
D.O., final effl. (p.p.m.)	2.8
Final effluent:	
B.O.D. (p.p.m.)	13
M.P.N.	3,000
Relative stability (days)	18
Receiving stream:	
Flow (c.f.s.)	371
B.O.D. above outfall (p.p.m.)	7
D.O. (p.p.m.)	4.5
Operating costs ($):	
Total for year	8,560.00
Per m.g.	155.00

[1] Due to experimental recirculation of waste activated sludge.

LABORATORY DIGESTER AND GASOMETER

By Walter A. Sperry

Superintendent, Aurora Sanitary District, Aurora, Ill.

In order to carry on miscellaneous digestion experiments from time to time without excessive monetary outlay for special equipment, the staff of the Aurora (Ill.) Sanitary District constructed some simple laboratory digesters and gas measuring equipment. All of these units are of sizes suitable for laboratory table use, yet are large enough to eliminate most of the disadvantages inherent in bottle-type units.

Digester Design

Details of the 10-gal. table digesters are given in Figure 1. Two of these units were made, with one used as a control and the other as the experimental variable. The main parts are of galvanized iron or copper tubing.

The tank (A) is 15½ in. tall and 14 in. in diameter. The gas dome (B), although made of galvanized iron in the Aurora version, could be made from a sound fruit can. A piece of ⅛-in. copper tube (F) is soldered in the top of the gas dome to lead the generated gas to a measuring device.

A ½-in. copper tube (C), positioned 3 in. below the top, serves to withdraw supernatant before adding the daily charge of sludge, which is introduced through the 1-in. pipe (E). This pipe has a long thread on the lower end and is screwed into a locknut soldered to the digester top. Thus, all gas escape is trapped.

To avoid drawing air into the digester when withdrawing supernatant, a glass or brass tee is connected in the gas line attached to tube (F). When the tank is being charged, a screw pinchcock on the tee leg is opened, permitting supernatant and sludge charges to flow without air binding. If necessary, a ½-gal. bottle is filled with gas and connected to the tee leg by a rubber tube reaching to the bottom of the bottle. This prevents any inflow of oxygen into the anaerobic atmosphere of the digester.

The liquid level is carried about ½ in. below the digester top to avoid scum in the gas dome and possible clogging of the gas tube.

A cleanout opening is provided at (D) by soldering a second 1-in. locknut firmly to the tank body. A nipple screwed into the locknut makes a base for screwing on a valve or cap.

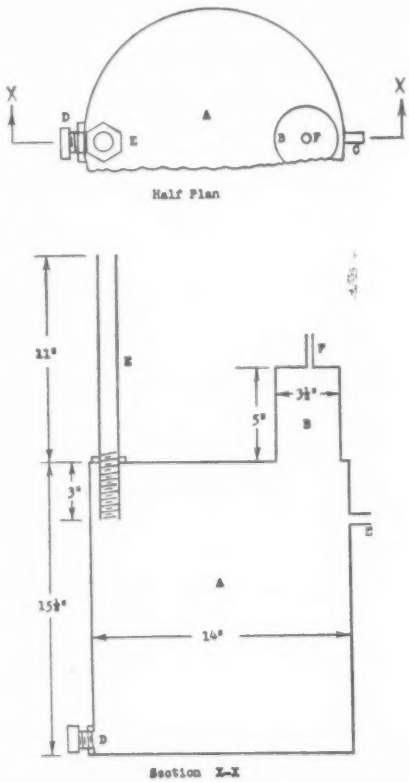

FIGURE 1.—Design details of laboratory table digester.

FIGURE 2.—Laboratory table gasometers serve as plant-made experimental gas measuring devices.

Temperature of the tank contents is readily recorded by a thermometer attached to a wire hook and hung in the fill pipe.

Obviously the design is suggestive only and the details can be varied to suit one's ingenuity or need.

Gas Meter Design

Measurement of the gas produced in the digester unit is accomplished simply and cheaply by laboratory gas meters (Figure 2) also made by the plant staff. As with the digester, two units were fabricated to provide control and flexibility. The units are actually substitutes for the wet meter instruments used in connection with a Junker gas calorimeter, and which are more expensive than the average sewage plant laboratory can afford.

The general design (Figure 3) is a small copy of the familiar gas holder of the local gas company or of a gas meter prover. It is constructed of galvanized iron and has details that can be varied to suit the requirements of the user.

The body of the meter (A) is 16½ in. in diameter and 18 in. high. The gas measuring chamber (B) is 15 in. in diameter, 17 in. high, and holds 0.102 cu. ft. per inch of height. By careful calculation and construction the gas chamber could be dimensioned to hold exactly 0.100 cu. ft. per inch, but the necessary construction precision would increase the cost of the device out of all proportion to the benefits derived.

A framework of light ½-in. angle iron (C) is bolted to the tank body (A) with stove bolts whose heads are soldered watertight on the inside. The framework is 37 in. high and supports

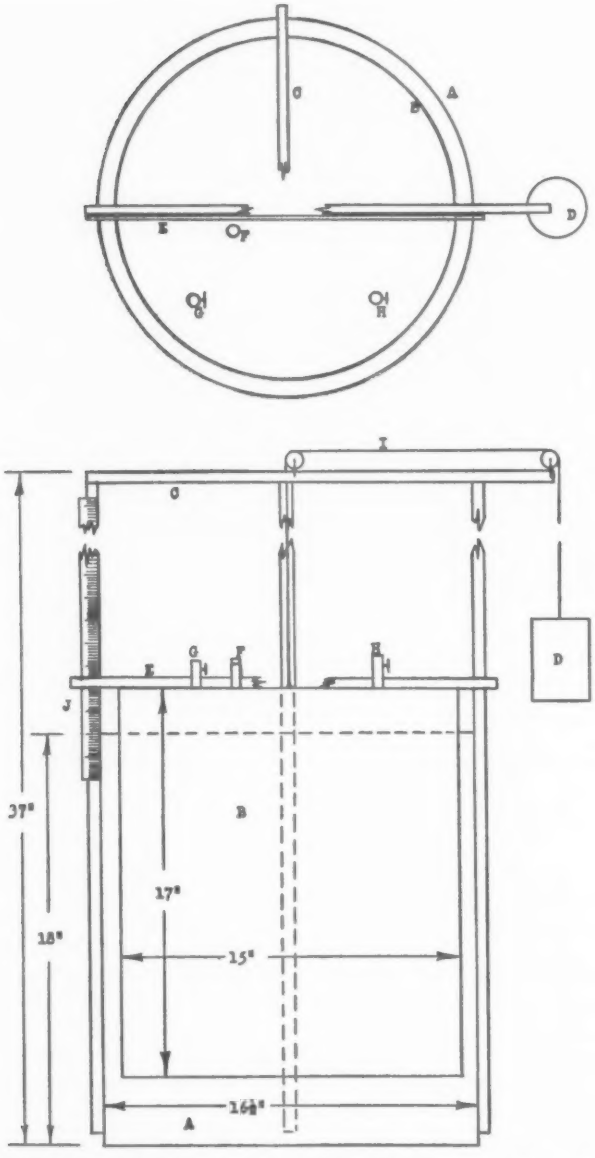

FIGURE 3.—Design details of laboratory table gas measuring device.

two light pulleys that support the gas holder by a light flexible cable (I) and a counterweight (D). The counterweight is a soup can filled with lead and so adjusted as to not quite lift the gas holder. The framework also supports an 18 in. ruler (J) as a measuring gage.

The top of the gas chamber (B) is equipped with two ¼-in. petcocks. Cock (G) is used for connecting the

rubber gas tube from the digester. Cock (H) is used for sampling the gas for analysis, or may be attached to a U-tube manometer to adjust the gas to atmospheric pressure before measurement if that refinement is desirable.

A ½-in. copper pipe tube (F) is soldered to the gas chamber top and closed with a firm rubber stopper to facilitate discharge of the gas from each day's measurement.

A ⅛-in. rod (E) is fastened to the top of the tank with three wire loops soldered to the tank. This rod, positioned just in front of framework (C), acts as a stop and zero point on the measuring scale (J). It should slide, but should not be loose.

The body of the meter is filled with a saturated solution of common salt, which prevents the solution of the gas in the liquor and thus avoids low gas volume readings and changes in gas composition. The upper edge of the gas holder and the inner rim of the tank are kept well coated with cup grease to reduce the tendency of the salt to crystallize the "creep" on the meter edges. An alternate plan would be to add about ¼ in. of machine oil to the liquid surface to prevent evaporation.

DIGESTER OPERATION IN AN INSTITUTIONAL PLANT *

By W. L. Edwards

Superintendent, Sewage Treatment Plant, Gowanda State Hospital, Gowanda, N. Y.

The sewage treatment plant at the Gowanda (N. Y.) State Hospital was put into operation in October, 1938. The plant affords primary treatment with separate sludge digestion, the digesters having been started without benefit of seed sludge.

Complete digestion of the sludge is accomplished in either of the two single-stage, circular, reinforced concrete tanks with fixed insulated covers, water-sealed gas domes, hot-water coils, and electrically-powered sludge and scum stirring equipment. Each tank is 26 ft. in diameter, 15.5 ft. in depth, and provides a capacity of 8,229 cu. ft. Pipes and valves are provided for taking sludge samples at the 2-, 5-, 8-, and 11-ft. depths, and overflow pipes allow for discharging the supernatant liquor back to the plant influent. The sludge pipes are so arranged as to pump sludge into the top and to withdraw it from the bottom. Re-circulation in either tank or between tanks is accomplished by valved inter-connections in the sludge lines.

Sludge is pumped twice each day, alternating digesters each time. Sludge is pumped until the sampling points at the pumps show very few solids. The sludge level in the tanks is increased about 3.5 in. per month in each digester. A sludge storage chamber is used in withdrawing sludge to facilitate removal and dewatering. By use of this chamber a measured quantity of sludge is removed in an operation separate from the vacuum filter.

Gas Production

Analysis of the sludge is made regularly from the different levels in the digesters for dry solids, volatile content, and pH. If the pH is below 7.0, lime is added to the primary settling tanks when pumping sludge to the digesters. The average pH is maintained at 7.1. The average dry solids content

* Presented at 1953 Annual Meeting, New York Sewage and Industrial Wastes Assn.; New York, N. Y.; Jan. 22–23, 1953.

is between 8.5 and 11.5 per cent, with a volatile content of 50.51 per cent. An analysis of the sludge is also made as it is pumped into the storage chamber, where the holding period is for one day at the most. There is no concentration of the sludge at this time, except for settlement and release of any entrained gas bubbles.

Hot water is circulated through the digester heating coils at not over 120° F. An average of 2,240 cu. ft. per day was circulated in 1952 to maintain the tank temperature within the mesophilic range at 90° F. An average of 2,800 cu. ft. of gas (0.87 cu. ft. per capita) was produced each day.

In 1951 the boilers were down and there was no way of heating the digesters. Immediately, gas production dropped, the sludge was of poor quality, and there was increase of sludge in the scum layer. No industrial wastes enter the plant, although the storm drains from the old group of buildings enter the sanitary system, and there is a comparatively great amount of canning wastes during the canning season.

Cleaning Problem

In June, 1951, the No. 1 digester was emptied to check the sludge mechanism, the hot-water coils, and the inside condition of the tank. At this time the gas dome had to be replaced due to corrosion, but the rest of the digester was in good condition. A total of 38,000 gal. (or 9 ft.) of sludge was withdrawn, which yielded 19 tons of dry solids with a volatile content of 48.96 per cent. By placing a fan and motor over the gas dome opening and circulating air into the digesters and out the scum manhole opening, the tank was purged of all gas. Air also was circulated while the work inside was being carried on.

Much silt and inorganic material was found piled around the outer edges of the sludge stirrers. Much inorganic material is thrown into the sewers by the patients at the state mental institution served by the plant. When removing some of this material from the digesters, by means of buckets hoisted out through the scum manhole, there were at least 5 cu. ft. of combs, toothbrushes, and other small items, besides the silt.

Rags a Nuisance

With the type of contributory population found in a mental institution, rags constitute a serious problem. It has been found necessary at times to backflush the sludge suction lines from the bottom of the digesters, due to a mat of rags forming around the sludge pipe openings. Naturally, when it is considered that from 3,000 to 13,000 pieces of linen are recovered at the coarse screen each month, some shredded rags get into the settling tanks, past the pumps, and into the digesters.

Sludge Removal

When drawing sludge, it has been found to be a good precaution not to take out an excessive amount of ripe material, but always to leave at least 1.5 ft. of seed sludge in the digesters. An attempt is made to obtain the best possible sludge for dewatering on the vacuum filter through proper digester operation. By operating the pumps at low speed, a hole is not drawn through the sludge blanket and the heavier seeded material is removed in a more even concentration, thus avoiding the removal of fresh or partially digested solids. By taking samples at the storage tank during sludge withdrawal, a thick consistency indicates the proper rate of removal.

During sludge withdrawal the gas domes are removed. As the sludge level is lowered, the scum is removed by means of a long-handled wire scoop and dumped into a truck for disposal. Nearly all the scum can be removed by this method, which to date has worked satisfactorily.

There never has been any foaming in the digesters, and over a period of

14 years there has been a minimum of trouble with the digesters and sludge digestion. By maintaining the proper temperature for digestion, the proper ratio of fresh solids to ripe sludge on a dry basis, and good mixing in the tanks, an odorless sludge with good drying and dewatering properties has been produced, together with a supernatant liquor having little odor.

TIPS AND QUIPS

Reverse English

An interesting if confusing bit of litigation regarding pollution of the River Lee by the Luton Corporation has occupied the attention of British courts since 1948, when the first injunction in the case was granted.

The Luton Corporation has spent huge sums on research, pilot-plant tests, and plant construction. One of the more promising phases includes rapid sand filtration of the effluent, similar to that used in water treatment plants.

An unusual turn was taken in the course of the affair last November, when the plaintiffs took exception to the high nitrate content of the effluent from the Luton sewage treatment plant, on the grounds that it encouraged the growth of certain water plants that are unattractive to trout, thereby causing the smothering or suppression of plants more favored by that fish. In commenting on this matter, a British periodical * makes the following notation:

"This is probably the first occasion on which a local authority has been asked to spend public money to decrease the stability of its sewage works effluent. This pressure for the reduction of nitrate is rather remarkable in view of the fact that one of the complaints against the Corporation concerns smell from Lord Brocket's lakes. Presumably the argument is that if nitrates are largely eliminated, there will be less plant growth, and therefore very little vegetation decaying in the water.

"One wonders how much of the trouble at Luton is due to interference with the natural flow of the stream, by such measures as the construction of weirs or ornamental lakes. It would appear equitable that if other folk are entitled to unpolluted water, sewage works are entitled to the use of a natural water course, and should not be held responsible for troubles provoked by interference with the natural flow of the river."

As the same commenter so aptly says: ". . . This seems good sense, but apparently it is not good law."

* *The Water & Sanitary Engineer*, **3**, 10, 364 (1953).

Insect Repellent

Now available in a special atomizer spray bomb, "Ticks-Off," a rotenone derivative in a vegetable oil base, is claimed to protect the user for 6 to 10 hr. against ticks, chiggers, mosquitoes, flies, ants, gnats, and other insect disease carriers. As with other rotenone products, Ticks-Off is completely harmless to humans and warm-blooded animals, and is said to be safe on normal skin, inoffensive to nasal passages, usable in the vicinity of foods without hazard, and nonstaining. Complete details are available from Mine Safety Appliances Company, Braddock and Meade Streets, Pittsburgh 8, Pa.

Ladder Safety Hints

Step Ladders

1. Ladders should not be more than 20 ft. in length at the side rails.

2. If in weak condition or damaged, ladders should be discarded at once.

3. When in use the ladder should be opened to full spread and have a locking device or spreader to firmly hold the sections in position.

Extension Ladders

4. Ladders should not be made of more than three sections.

5. When fully extended, an extension ladder should not exceed 55 ft. in length.

6. Each side section of an extension ladder should be raised and lowered by means of a rope and pulley and should be equipped with two automatic locks of an approved design.

Straight Ladders

7. Ladders should not be more than 30 ft. in length.

8. Width between side rails at the base of straight ladders should be not less than 12 in. for ladders up to 12 ft. in length, with an increase of ¼ in. for each additional foot of length.

9. Ladders should be securely fastened or braced to prevent movement or shifting, and should be equipped with safety feet.

10. Ladders should be long enough to extend not less than 42 in. above any platform or landing which they serve.

11. Ladders should not be spliced together to make a longer ladder. Neither should they be set on boxes or other objects to obtain additional height.

12. Ladders should be maintained in good condition at all times. Weak ladders should be discarded.

13. Store ladders in a dry place, off the ground, and out of the sun.

14. Do not paint ladders, as cracks and defects may be hidden by the paint.

Carbon Monoxide

Although carbon monoxide poisoning is usually thought of as a cold-weather hazard because of closed cabs, windows, and ventilators, it can be just as potent a danger in the open summer air. In fact, the experience at one plant in this regard may be of more than passing interest.

The monoxide generator in question happened to be a gasoline-powered mowing machine, whose operator walked behind to steer in the usual manner. Little did he realize that in doing so he was constantly breathing the exhaust fumes. Naturally, the exhaust contained a high percentage of carbon monoxide, which although odorless, colorless, and non-irritating is lethal in concentrations as low as 1 per cent. Further, the hot humid weather and the operator's exertion increased the effect of the gas on his system.

The true circumstance was first realized when the operator developed a headache, weariness, dizziness, nausea, and increased difficulty in breathing. Continued exposure could well have been fatal, but quick action on the part of supervisory and medical personnel averted a tragedy.

Moral: Check all internal combustion equipment to eliminate exhaust defects and poor ventilation facilities.

Ah! Paree!

The famous sewers of Paris, locale of much action in the golden age of French literature, are being restored to their "classic" condition under a huge rebuilding program scheduled to be completed this year. The restoration is aimed at making up for wartime neglect.

Some of the incentive for the work is supposedly a bid for tourist traffic, as the sewer boat rides (see THIS JOURNAL, **23**, 3, 322; Mar., 1951) are to be more widely publicized. Perhaps one will even be able to enjoy the "rubberneck" aspects with the modern decor.

Reviews and Abstracts*

Point of Discharge of Wastes into a Stream. By S. A. Nesmejanow. *Gigiena i Sanitaria* (Russia), 11 (1951). Abs. in *Gaz, Woda i Tech. Sanit.* (Poland), 26, 9, 271 (1952).

A formula is given for calculating the point of discharge of wastes into a stream to prevent the possible contamination of the river water near the bank, which is used for recreational purposes. In this expression, $l = \frac{q}{h\,v\,n}$, l = distance from the bank to the point of discharge, q = volume of wastes discharged, h = depth to point of discharge from surface of stream, v = velocity of the river, and n = a dilution factor. For domestic wastes the required dilution factor ranges from 1:500 to 1:1,000, bath waters 1:200 to 1:300, laundry wastes 1:500 to 1:1,000, and the dilution factor for industrial wastes should be determined in the laboratory. For most industrial wastes the required dilution factors range from 1:500 to 1:1,000. With small volumes of waste the value of l will be small, and the calculation is straightforward. It is more difficult to make this calculation for lakes, ponds, and the ocean, in which there is no simple velocity relationship. Additional work is under way to study the dispersion of wastes in rivers.

Conrad P. Straub

Some Notes on Sewage Analysis. By W. F. Hester and R. D. Raybould. *Jour. and Proc.*, Inst. Sew. Purif. (Brit.), Part 4, 392 (1950).

Part 1. The Determination of Anion-Active Detergents in Sewage Effluents.

The method involves addition of methylene blue and sulfuric acid to detergent solutions of known strength, extraction with chloroform, and determination of color intensity with an Eel colorimeter. Calibration curves are made and results obtained from a like test on sewage are matched against the curve.

Thiocyanate and nitrate nitrogen interfere with the test. The effect of thiocyanate was eliminated by precipitation with silver sulfate solution. A calibration curve for nitric nitrogen permits corrections to be made for interfering nitrates.

The modified Shell method, which involves extraction at different pH levels, was found to require more time, to eliminate the effect of naturally occurring organic substances, and to require the same precaution for thiocyanates and nitrates.

Part 2. Analysis of Sewage Sludge.

Phosphate is determined by treating with ammonium molybdate solution, filtering, dissolving the precipitate in standard sodium hydroxide, then back-titrating with acid. Nitrogen is determined by boiling dried sludge with selenium oxychloride catalyst, diluting, and distilling into hydrochloric acid. Excess acid is titrated with sodium hydroxide. pH is determined by using barium sulfate with the indicator.

Free sulfate is found by using barium chloride to react with sulfates. Eschka's mixture and heat followed by bromine water will oxidize sulfides to the sulfate, following which barium chloride is again used.

Before determining metallic constituents, sludge is boiled with nitric and hydrochloric acids and evaporated to destroy organic material. This residue is boiled with hydrochloric acid until the silica shows white and can be filtered out.

The acidified solution is boiled and gassed with hydrogen sulfide. Precipitated sulfides are removed by filtering and the filtrate is saved.

Separated sulfides are removed from the paper with hot nitric acid. This solution

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 325 Illinois Bldg., Champaign, Ill.

is nearly evaporated, then diluted, boiled, and filtered to remove stannic oxide. Bismuth is precipitated from the filtrate by partially evaporating and treating with ammonium nitrate solution. Treatment of this filtrate with sulfuric acid, partial evaporation, and cold water precipitates lead sulfate. Copper is precipitated by using hydrogen sulfide, dissolving the filtered precipitate in nitric acid and obtaining the concentration from color standards. The filtrate after copper is removed is partially evaporated and treated with acid, Rochelle salt, potassium iodine, and β-naphthaquinoline to precipitate a cadmium compound, which is removed, dissolved in ammonium hydroxide, and titrated with potassium iodate for cadmium determination.

Filtrate from the original sulfide precipitation is boiled, oxidized with nitric acid, made alkaline with ammonia and ammonium chloride, boiled, and filtered. The filtrate is saved. The precipitate is treated with sodium peroxide, boiled, and the precipitate of ferric hydroxide filtered off. This filtrate is further boiled with ammonium chloride to precipitate aluminum hydroxide. The acidified filtrate is then reduced with ferrous ammonium sulfate and back-titrated with potassium permanganate to determine chromium.

The first filtrate from the iron determination is saturated with hydrogen sulfide, filtered, and the filtrate set aside. Precipitated sulfides are made acid and filtered, the precipitate containing nickel and cobalt. Zinc in this filtrate is determined by titration with potassium ferrocyanide. Precipitate is dissolved in aqua regia, further precipitated with sodium carbonate, filtered, and dissolved in hydrochloric acid. One portion of the solution is treated with dimethyl glyoxime to precipitate nickel and the other with α nitroso-β-naphthol to remove cobalt.

The filtrate saved is made ammoniacal and calcium is precipitated with ammonium oxalate solution. Magnesium is removed from the filtrate by adding ammonium phosphate solution and ammonia, filtering, and igniting the filtrate.

W. A. HASFURTHER

Experiments at Mogden on the Evans' Modified Methylene Blue Method for the Estimation of Anionic Detergents in Sewage. By S. E. KAY. *Jour. and Proc.*, Inst. Sew. Purif. (Brit.), Part 4, 403 (1950).

This method involves measuring the depth of the blue color soluble in chloroform formed by the interaction of the active agent and methylene blue at two different hydrogen ion concentrations. The different pH values are obtained by using acetate-sulfuric acid buffer solutions. Experimental data show that extraction with chloroform of the complex formed between methylene blue and anion-active detergents is unaffected by changes in pH, whereas the extraction with chloroform of the complexes formed between methylene blue and nitrates, thiocyanates, and compounds occurring in urine is decreased with decrease in pH.

Tests were made on three buffered solutions at six different pH's, one solution containing the detergent (Teepol) only, another potassium thiocyanate, and the other both detergent and thiocyanate. A table and graph show the definite interference due to the thiocyanate. A like test using potassium nitrate also showed an interfering effect, but much less than that of thiocyanate.

Urine contains substances which give a blue complex under the conditions of the methylene blue method for the estimation of anionic detergent. Three buffered urine solutions at six different pH levels were used. A graph and a table show that the effect of anion-active bodies in urine is not eliminated by this proposed method. It is concluded that no completely satisfactory method for the determination of anionic synthetic detergent has yet been described. W. A. HASFURTHER

Further Operation of an Enclosed Filter at Dalmarnock Sewage Works. By W. M. CAMERON AND A. R. JAMIESON. *Jour. and Proc.*, Inst. Sew. Purif. (Brit.), Part 4, 417 (1950).

General results and average monthly operation data for nearly seven years are given, but discussion and loading details cover a 2½-year period. The filter is 18 ft. deep, with most of the rock being of 1½- to 2-in. diameter. Great variations in loading are due to industrial wastes, particularly gas plant liquors.

The filter ponded at rates of 6 to 12 m.g.a.d. (Imp.) and conditions improved but little when rates of 2 to 8 m.g.a.d. with 1:1 recirculation were tried. Even when starting with a clean filter, recirculation had but a limited benefit.

B.O.D. loadings without recirculation ranged from 400 to 1,266 lb. per acre-foot, with reductions through the filter ranging from 79.9 to 92.2 per cent. Purification was checked by numerous grab samples at depths of 6, 9, and 15 ft., and it was found that a high proportion of work was done in the upper 6 ft. Results over a year's time show that with total reduction through the filter ranging from 80.2 to 90.9 per cent, reduction through the upper 6 ft. ranged from 53.5 to 91.3 per cent.

A fan was installed for ventilation of the filter, but did not aid any in improving the D.O. of the effluent. It did increase nitrification, eliminate egress of insects, and hold down slight odors.

W. A. HASFURTHER

Some Problems in the Chlorination of Sewage. By H. WILSON. *Jour. and Proc.*, Inst. Sew. Purif. (Brit.), Part 4, 433 (1950).

The author briefly discusses variations in the degree of bacterial destruction by equal doses of chlorine in various towns. He summarizes results of Wyckoff (*Sewage Works Jour.*, **21**, 3, 484; May, 1949), showing that dosages of 0.5 p.p.m. and 5-min. contact time gave equally as good results as higher dosages. The author's work with hypochlorite showed similar results part of the time, but wide variations were frequent. Chlorination of septic sewage resulted in very poor bacterial results.

Mixing is important, and many believe that violent agitation has a part in destroying bacteria. The author discusses experiments of other workers and his own beliefs on the role played by violent agitation.

W. A. HASFURTHER

Discharge of Sewage and Industrial Wastes to Estuaries. By B. A. SOUTHGATE AND W. S. PREDDY. *Jour. Royal San. Inst.*, **72**, 4, 424 (1952).

Some of the effects of pollution in the estuaries of the Tees, Mersey, and Thames, as determined by surveys, are presented. In addition, methods are outlined whereby it is hoped to obtain more generalized information on the effects of pollution in estuaries. Sections are included on the formation of mudbanks, the current system, concentration of dissolved oxygen, fisheries, plants and invertebrate animals, and the treatment of polluting liquors discharged to estuaries.

Among the significant conclusions advanced by the authors in this paper are:

1. No generally applicable chemical method of analyses is now available for distinguishing muds from polluted and unpolluted localities.

2. No evidence was found in the survey of the Mersey estuary that the rate of formation of mudbanks was significantly affected by polluting materials.

3. Methods presently in use are unsatisfactory in predicting dissolved oxygen deficiencies in estuaries.

4. The distribution of plants and invertebrates followed a similar pattern in all estuaries examined, whether polluted or unpolluted.

The authors are presently engaged in studies to determine the relative influence of temperature and wind on the level of dissolved oxygen saturations in estuaries, the minimum amount of dissolved oxygen concentrations necessary in estuaries to prevent the formation of hydrogen sulfide, and the general circulation of waters in an estuary, which last is presented in some detail in the paper.

ALEX N. DIACHISHIN

Some Practical Aspects of Storage and Stormwater Sewer Design. By E. DIXON GRUBB. *Surveyor*, **111**, 811 (1952).

This article continues the discussion of "storage" in storm sewers, which was the subject of two other recent papers in the same journal (**111**, 627 and 679). Considerations introduced are supplementary, and in some respects contradictory, to those forming the basis of the earlier publications.

M. C. RAND

Some Factors in the Treatment of Sewage in Percolating Filters. By T. G. TOMLINSON AND H. HALL. *Jour. Inst. Sew. Purif.*, Part 4, 338 (1950).

Data cover a year's operation on eight experimental filters at rates from 100 to 1,000 g.p.d. (Imp.) per cubic yard (approximately 1 to 10 m.g.a.d. for a 6-ft. filter). One filter contained mostly large gravel 2 to 3 in. in diameter, and the others contained crushed gravel, mostly $\frac{3}{4}$ to $1\frac{1}{2}$ in. in diameter. The distributor waved backwards and forwards over the rectangular units so the center was dosed twice as often as the edges.

Most results are shown by figures and graphs. With settled raw sewage having a B.O.D. of 150 p.p.m., filter effluents when settled 1 hr. had B.O.D.'s ranging from 25.7 to 58.0 p.p.m., the figure increasing with the rate of application. Settled filter effluents were filtered through paper and it was found that removal of the suspended solids reduced the B.O.D. by 20 to 30 per cent.

Considerable study was given to the growth and distribution of film and sludge in the filter. Units operated at rates from 300 to 1,000 g.p.d. per cubic yard ponded regularly and severely, except for the one with the large gravel, which ponded but little when operated at a dosing rate of 600 g.p.d. per cubic yard. Appreciable amounts of film were found at all depths, but at higher rates the amount decreased with the depth. Types of material and amounts on the rock at various depths are shown in tables. Even at high rates there was no evidence of scouring in the filter.

Much of the paper is given to a discussion of equations showing the rate of removal of oxidizable matter in a percolating filter, velocity constants, and time of contact. W. A. HASFURTHER

The Treatment of Gas Works Liquor in Admixture With Sewage in Percolating Filters. BY W. H. BLACKBURN, T. G. TOMLINSON, AND T. H. SUMMERS. Publ. G. R. B. 63 of The Gas Research Board, Beckenham, Kent, England (1952).

Results were reported of experiments on the effect of (a) spent gas liquor, and (b) fractions of crude gas liquor on biological filtration of settled sewage.

The trials with spent gas liquor were made in two large-scale percolating filters. Addition of the liquor in a concentration of 0.5 per cent by volume caused a significant deterioration in the chemical quality of the effluent and caused some increase in intensity of color.

Crude liquor was divided into six fractions, by an unusual method, giving the following components:

1. Phenol.
2. Cresols, xylenols, and some phenols.
3. Catechol and homologues.
4. Resorcinol and homologues.
5. Neutral oils and bases.
6. Carboxylic acids, some phenols, and "humic acids."

The trials with the fractions of crude liquor were made in small percolating filters, each 1 ft. in diameter. The greatest deterioration in quality of sewage effluent was caused by the addition of two fractions, one containing thiocyanate, ammonia, and organic substances not extracted from the crude liquor by methyl isobutyl ketone, and the other containing carboxylic acids and "humic acids." Of the four fractions into which the phenols were divided, the two containing polyhydric phenols caused a significantly greater deterioration in the quality of the effluent, as measured by the test for oxygen absorbed from permanganate, than did the two containing monohydric phenols, but the effect of all four fractions on the biochemical oxygen demand of the effluent was very similar. The bearing of these results on the practice of hot gas detarring is discussed. K. W. COSENS

BOOKS, REPORTS, AND PAMPHLETS

Tentative Standard Specifications for Steel Pipe Flanges. Amer. Water Works Assn. Price, $0.25 (1952).

Proceedings of the Illinois Association of Sanitary Districts (1952). (Secretary: J. R. Longley, Peoria, Ill.)

1953 Annual Report. Interstate Sanitation Commission, New York, N. Y. 41 pp. + 7 illus. (1953).

Mohawk River Drainage Basin. Mohawk River Drainage Basin Survey Series Report No. 2, N. Y. State Water Poll. Control Board, Albany, N. Y. 245 pp. (1952).

Alum. Industrial Chemicals Div., American Cyanamid Co., New York, N. Y. (1953).

A 43-page booklet on commercial aluminum sulfate, outlining its numerous industrial applications. Of particular interest is a 5-page section on "Alum in the Treatment of Sewage and Industrial Wastes."

The Sanitary District of Rockford, Illinois. 56 pp. (1952).

A history of the District from 1926 to 1951, with a summary of operations covering the decade 1940–1951.

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Proceedings of Member Associations

CANADIAN INSTITUTE ON SEWAGE AND SANITATION

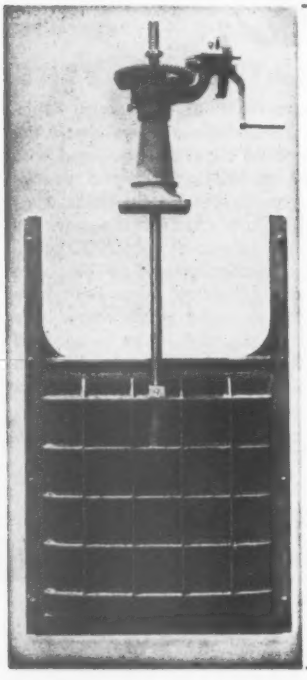
The 19th Annual Convention of the Canadian Institute on Sewage and Sanitation was held at the Seigniory Club, Montebello, P. Q., on November 3–5, 1952. Registration totaled 273, of whom 74 were ladies.

After a pre-convention social evening on November 2, the sessions opened on November 3 with a guided discussion on "Financing of Subdivision Utilities." This was followed by the Convention Luncheon and a symposium on "The Investigation of Pollution in the Spanish River," by a panel consisting of A. V. DeLaporte, Chemical Engineer, Ontario Department of Health, Toronto; R. Ferguson, University of Toronto; J. Wilkinson, City Department of Health, Toronto; and Ian G. Simmonds, Chemical Engineer, Ontario Department of Health, Toronto. The session closed with a guided discussion on "A Plumbing Code in Municipal Sanitation."

The morning session on November 4 opened with the Annual Business Meeting, followed by papers on "Research on Treatment of Milk Plant Wastes," by N. D. Woolings, Imperial Oil Ltd., Montreal, and "Sludge Disposal Methods for Canadian Conditions," by N. S. Bubbis and D. C. McClean, respectively General Manager and Superintendent, Greater Winnipeg Sanitary District, Winnipeg, Man.

After luncheon the guided discussions were continued, then the re-

(*Continued on page 272a*)



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mainder of the afternoon was given over to enjoyment of the many recreational facilities of the Seigniory Club. The evening was occupied with the Annual Banquet and an entertainment provided by the Canadian Sanitation Equipment Association.

The morning session on November 5 comprised a paper on "Sanitary Fill as a Method of Refuse Disposal," by G. H. Richards, City Engineer, Brantford, Ont., and guided discussions on "Sewer Cleaning and Maintenance" and "Miscellaneous Problems in Sanitation."

A "Club Room," courtesy of the Canadian Sanitation Equipment Association, was open at various times throughout the meeting when technical sessions were not being held.

Officers elected for 1952–3 were:

President: G. H. Baker, North York Township, Ont.
Vice-President: A. E. Chalmers, Peterborough, Ont.
Secretary-Treasurer: A. E. Berry, Toronto, Ont.

A. E. BERRY,
Secretary-Treasurer

TEXAS WATER AND SEWAGE WORKS ASSOCIATION

The 1953 Annual Meeting of the Texas Water and Sewage Works Association, held in conjunction with the 34th Annual Short School at Texas A. & M. College, College Station, Tex., March 8–12, 1953, recorded a total of 750 registrants. This made the fifth consecutive year of all-time record attendances, the 1952 total having been 625.

In addition to the usual short school lectures, demonstrations, and laboratory work, the papers of especial interest were presented as follows:

"Deep Well Disposal of Chemical Waste," by H. O. Henkel, E. I. du Pont de Nemours Co., Inc., Victoria.

"Disposal of Salt Water Wastes," by W. S. Morris, East Texas Salt Water Disposal Co., Kilgore.

"Activated Sludge in Industrial Waste Disposal," by D. Hatfield, Southwest Foundation for Research and Education, San Antonio.

"The Air We Breathe," by Henry Herndon, Special Service Engineer, Texas Employers Insurance Association, Employers Casualty Co., Dallas.

"Panel Discussion," by representatives of various state and federal regulatory agencies.

"Organic Catalysts in Sewage Treatment," by R. E. McKinney, Head, Dept. of Sanitary Science, Southwest Foundation for Research and Education, San Antonio; A. J. Krell, Reliance Chemicals Corp., Houston; and W. C. Beaver, Jr., Market Coverage, Inc., Everett, Wash.

"New Products and Pollution Prevention," by R. W. Haywood, Jr., E. I. du Pont de Nemours Co., Inc., Wilmington, Del.

"Active Participation in Technical Associations as a Means of Self-Advancement," by M. J. Blew, Chief, Water Supply and Sanitary Services Div., Repairs and Utilities Section, Chief of Engineers' Office, Washington, D. C.

"Plating Bath Disposal," by Richard A. Springer, Bell Aircraft Corp., Fort Worth.

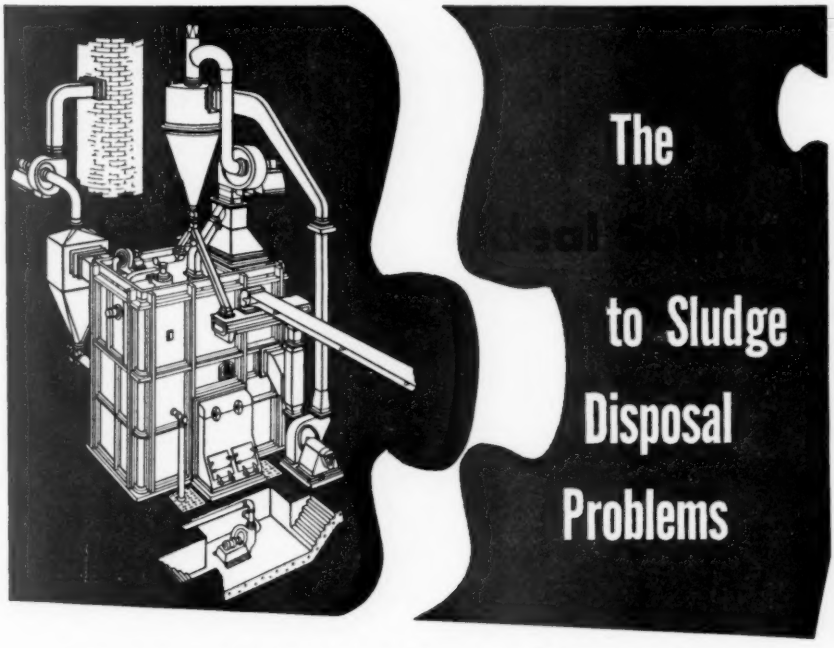
"Oil-Water Separation," by G. A. Rohlich, Professor of Sanitary Engineering, University of Wisconsin.

"Determination of Excessive Emission of Air Pollutants," by E. M. Adams, Assistant Director, Biochemical Research Dept., Dow Chemical Co., Midland, Mich.

"Air Pollution," by Henry Doyle, Chief, State Aid Branch, Division of Occupational Health, USPHS, Washington, D. C.

"Effect of Enzymatics and Bionetics on the Performance of Activated Sludge on Industrial Wastes," by Ross E. McKinney, Head, Dept. of Sanitary Science, Southwest Foundation of Re-

(*Continued on page 274a*)



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Chicago, Ill. (W. Southwest)	City Engineering Dept.
Edgewater, N. J.	McClave & McClave
Fond du Lac, Wis.	Jerry Donohue Engrg. Co.
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San Diego, Cal.	Frank Currie
San Francisco, Cal.	Clyde C. Kennedy
Schenectady, N. Y.	Havens and Emerson
Sheboygan, Wis.	Jerry Donohue Engrg. Co.
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search and Education, San Antonio.

"Air Pollution," by a panel comprising M. C. Wukasch, W. Quebedeaux, and W. H. Bell, Texas State Dept. of Health, Austin.

At the Annual Business Luncheon of the Sewage and Industrial Wastes Section, the Federation's Arthur Sidney Bedell Award was presented to W. S. Mahlie.

The following officers were elected to serve the Sewage and Industrial Wastes Section during 1953–4:

Chairman: A. C. Bryan, Houston.
Vice-Chairman: K. Mills, Texas City.
Temporary Vice-Chairman: W. S. Mahlie, Fort Worth.
Secretary: V. M. Ehlers, Austin.
Assistant Secretary-Treasurer: Mrs. Earl H. Goodwin, Austin.

MRS. EARL H. GOODWIN,
Assistant Secretary-Treasurer

NEW ENGLAND SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 24th Annual Fall Meeting of the New England Sewage and Industrial Wastes Association was held at the Taunton Inn, Taunton, Mass., on November 5, 1952. The total registration was 144 members and guests, including 20 ladies.

The program opened with the annual business meeting, at which the following officers were elected for 1953:

President: Eugene L. Bond, Greenfield, Mass.
1st Vice-President: Charles G. Hammann, Providence, R. I.
2nd Vice-President: Walter E. Merrill, Boston, Mass.
Secretary-Treasurer: Stephen M. Hurley, Jr., Providence, R. I.

The technical program included the following papers:

"Symposium on Sewer Maintenance Problems," by a panel consisting of George M. Granger, Deputy Superintendent of Sewers, Springfield, Mass.; Forrest F. Harbour, Superintendent of Sewer Lines, South System, Met. Dist. Commission, Boston, Mass.; Paul C. Hedenstad, Superintendent of Sewers, Worcester, Mass.; and A. E. Maynard, City Engineer, Nashua, N. H.

"Design and Operation of the Taunton Sewage Disposal Works," by Frank L. Heaney, Senior Engineer, Fay, Spofford & Thorndike, Boston.

"Pollution Control on the Rumford River," by Worthen H. Taylor, Senior Sanitary Engineer, Mass. Dept. of Public Health.

The program closed with inspection trips to the Taunton sewage treatment plant, and the Hercules Powder Company plant and Mansfield Bleachery in Mansfield, Mass.

WALTER E. MERRILL,
Secretary-Treasurer

LOUISIANA CONFERENCE ON WATER SUPPLY AND SEWERAGE

The 1953 Annual Meeting of the Sewage Works Section, Louisiana Conference on Water Supply and Sewerage, was held at Louisiana State University, Baton Rouge, La., on March 18–20, 1953, in conjunction with the 16th Annual Short Course. Registration totaled 110.

Papers presented at the sewage section meetings stressed equipment maintenance and repair, reduction of infiltration, and cross-connection elimination, in addition to the regular short course subjects.

Officers elected to serve during 1953–4 were:

Chairman: L. C. Eldridge, Baton Rouge.
Vice-Chairman: J. L. Love, Lafayette.
Secretary-Treasurer: G. H. West, Lake Charles.

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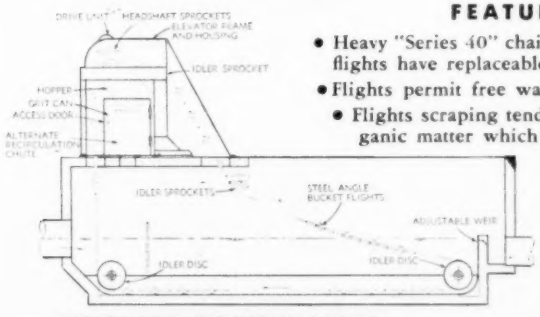

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Flow Controls—Equipment for measurement on control of liquids and gases is described in Catalog 003, together with specifications and operating characteristics.—Simplex Valve & Meter Co., 68th and Upland Sts., Philadelphia 42, Pa.

Enclosed Motors—New Bulletin 1784 gives specifications and data on totally-enclosed motors in 1- to 75-hp. sizes.—U. S. Electrical Motors, Inc., Box 2058 Terminal Annex, Los Angeles 54, Calif.

Portable Generator—New dual-voltage 5-kw. portable generator powered by air-cooled, 2-cycle gasoline engine is described in a new brochure.—Homelite Corp., 67 Riverdale Ave., Port Chester, N. Y.

Vacuum Switch—A vacuum switch alarm particularly suitable for installation on sludge pump suctions is described in new release.—Jaycon Associates, 404 N. Washington Ave., Minneapolis, Minn.

Self-Priming Pumps—Bulletin 5300 describes a new line of self-priming, high-capacity centrifugal pumps for handling liquids with high solids contents.—Ralph B. Carter Co., Hackensack, N.J.

Industrial Waste Treatment Guide—A new 8-page bulletin (B-I-F No. 4) contains a highly useful table showing the different types or combinations of unit treatment processes for more than 50 wastes, together with the equipment used in the several unit treatment processes.—B-I-F Industries, Inc., 345 Harris Ave., Providence, R. I.

Hand Portable Arc Welder—Information on 110/220-v. a.c., hand, portable welder is contained in a catalog sheet.—Royal Equipment Corp., 906 Main St., Burbank, Calif.

Engine Stop Valve—Application and design data for "cushioned" automatic engine stop valves are given in new 6-page Bulletin S-3.—Golden-Anderson Valve Specialty Co., 2125 Keenan Bldg., Pittsburgh 22, Pa.

Roller Chains and Sprockets—Catalog 52-1 gives complete specifications and other data on roller chains and sprockets.—Baldwin-Duckworth Div., Chain Belt Co., Dept. P.R., Springfield 2, Mass.

Chemical Feed Pumps—New 4-page Bulletin H-20-M describes applications, capacities, etc., for controlled volume, positive displacement, solution feed pumps.—Milton Roy Co., 1300 E. Mermaid Lane, Philadelphia 18, Pa.

Anti-Rust Paints—A new 2-page Bulletin L-6976 describes anti-rust paints requiring no surface preparation.—Paramount Industrial Products Co., University Center Station, Cleveland 6, Ohio.

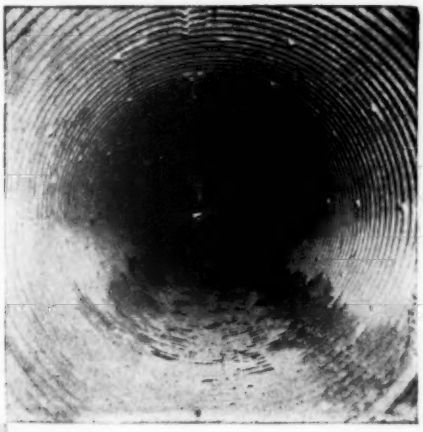
Flexible Metal Hose—Technical Data Book U-111 gives complete information on application and design data for all types of flexible metal hose.—Universial Metal Hose Co., 2133 S. Kedzie Ave., Chicago, Ill.

Condensation Control—Charts provide specific temperature data and efficiency ranges of Insul-Mastic Type "D" in controlling condensation on cold pipes and other metal.—Insul-Mastic Corp., 1141 Oliver Bldg., Pittsburgh 22, Pa.

Air Diffuser Plate—An improved aluminum oxide air diffuser plate for activated sludge use is described in literature recently released.—Electro Refractories & Abrasives Corp., Buffalo, N. Y.

Gas and Diesel Engines—Bulletin L-71 gives engineering data and specifications on gas, diesel, and gas-diesel engines, supercharged or not, in sizes from 690 to 2,500 hp.—Cooper Bessemer Corp., Mount Vernon, Ohio.

Which Sewer



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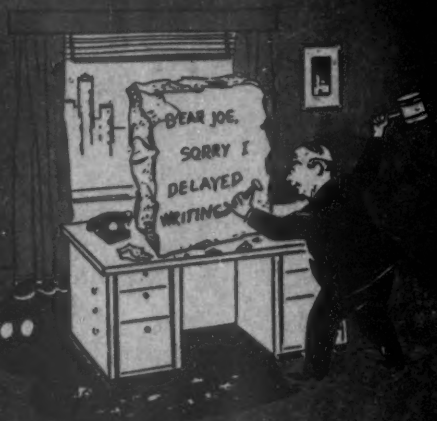

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